QE
1
G5
vol. 61
1950

PROCEEDINGS

OF THE

GEOLOGISTS' ASSOCIATION

(FOUNDED 1858)

VOLUME THE SIXTY-FIRST
1950

Edited by
K. S. SANDFORD

(Authors alone are responsible for the opinions and facts stated in their respective papers, and for the accuracy of their references)

COLCHESTER :
BENHAM & CO. LTD.
1950

6 Feb 69

OFFICERS AND COUNCIL

Elected March, 1950

President : T. EASTWOOD, A.R.C.S., M.I.M.M., F.G.S.

Vice-Presidents : E. C. MARTIN, O.B.E., B.SC., A.R.I.C., F.G.S. ; A. WRIGLEY ; G. W. HIMUS, PH.D., M.I.CHEM.E., F.G.S. ; A. G. BELL, I.S.O., B.SC., F.G.S. ; E. ERNEST S. BROWN, M.B.E., F.G.S.

Treasurer : R. W. POCOCK, D.SC., F.G.S., 43, Exeter Road, Brondesbury, London, N.W.2.

Secretaries :

General : R. REELEY, F.G.S., H.M. Geological Survey and Museum, South Kensington, S.W.7.

Field Meetings : H. A. HAYWARD, O.B.E., F.G.S., 7, Little Woodcote Lane, Purley, Surrey.

Publications Committee : A. J. BULL, PH.D., M.SC., F.G.S., 6, Bolt Court, Fleet Street, London, E.C.4.

Editor : K. S. SANDFORD, M.A., D.SC., D.PHIL., F.G.S. ; University Museum, Oxford.

Librarian : L. R. COX, M.A., SC.D., F.G.S., British Museum (Nat. Hist.), South Kensington, S.W.7.

Other members of the Council :

Miss M. A. ARBER, M.A., F.G.S., F.R.G.S. (1947).
T. BARNARD, B.SC., PH.D., D.I.C., F.G.S. (1949).
S. BUCHAN, B.SC., PH.D., F.G.S. (1946).
A. J. BUTLER, O.B.E., M.SC., F.G.S. (1949).
W. DACK, I.S.O., F.G.S. (1949).
T. F. GRIMSDALE, B.SC., F.G.S. (1950).
J. F. KIRKALDY, D.SC., F.G.S. (1950).
C. D. OVEY, B.SC., F.G.S. (1949).
H. W. PICKWORTH, F.R.M.S. (1950).
Miss MABEL TOMLINSON, B.A., D.SC., PH.D., F.G.S. (1946).
D. WILLIAMS, M.SC., PH.D., B.E., F.G.S. (1946).
C. W. WRIGHT, M.A., F.G.S. (1947).

CONTENTS

PAGE

Annual Report of the Council 87

Baden-Powell, D. F. W. Report of Field Meeting in the Lowestoft District 191

Barnard, T., J. G. Capewell and W. D. Lang. Whitsun Field Meeting at Lyme Regis 156

Bell, A. G. and R. J. Bell. Report of Field Meeting at Eynsford, Kent ... 302

Bell, R. J. and A. G. Bell. Report of Field Meeting at Eynsford, Kent ... 302

Brown, E. Ernest S. The Story of Quartz Crystals 1

————. Postscript to The Presidential Address 12

Bull, the late Dr. A. J. Gravitational Sliding 198

Burnaby, I. P. The Tubular Chalk Stacks of Sheringham 226

Burton, E. St. John and D. Curry. Report of Field Meeting at Barton and Milford-on-Sea, Hants. 161

Capewell, J. G., W. D. Lang and T. Barnard. Whitsun Field Meeting at Lyme Regis 156

Casey, R. The Junction of the Gault and Lower Greensand in East Sussex and at Folkestone, Kent 268

Channon, P. J. New and enlarged Jurassic Sections in The Cotswolds ... 242

Cox, L. R. Report of Field Meeting in the Cotswolds 261

Curry, D. and E. St. John Burton. Report of Field Meeting at Barton and Milford-on-Sea, Hants. 161

Davis, A. G. The Radiolaria of the Hawasina Series of Oman 206

Epps, F. J. Report of Field Meeting to Charlton, Plumstead and Abbey Wood 218

Hayward, J. F. Report of Field Meeting—Two Buried Rivers in London 225

Higginbotham, I. E. Report of Field Meeting at Lewes, Berwick and Newhaven 299

Kirkaldy, J. F. Solution of the Chalk in the Mimms Valley, Herts. ... 219

————. Report of Field Meeting at Water End, North Mimms... ... 224

Lacaille, A. D. The Chronology of the Deglaciation of Scotland ... 121

Lang, W. D., T. Barnard and J. G. Capewell. Whitsun Field Meeting at Lyme Regis 156

Ovey, C. D. and J. D. H. Wiseman. Recent Investigations on the Deep-Sea Floor 28

———— ————. Demonstration at the British Museum (Natural History) 85

Pocock, R. W. Report of Whitsun Field Meeting 202

Sparks, B. W. Report of Field Meeting on the South Downs 163

Thompson, H. R. Some Corries of North-West Sutherland 145

Wiseman, J. D. H. and C. D. Ovey. Recent Investigations on the Deep-Sea Floor 28

———— ————. Demonstration at the British Museum (Natural History) 85

Wright, C. W. and E. V. Some Dromiacean Crabs from the English Cretaceous 13

LIST OF PLATES

PLATE — FACING PAGE

1. Dromiacean Crabs from the English Cretaceous 13
2. Recent Cold and Temperate Water Planktonic Foraminifera... ... 67
3. Recent Warm Water Planktonic Foraminifera 70
4. View in Glen Falloch, Perthshire ; Ben More (3,843 ft.) in background ; relics of the deglaciation and native pines in centre ; self-grown alders, birches, hazels and oaks fringeing stream in foreground 126
5. Fernhurst Sandstone dipping northward in road cutting south of village. Rubble drift in road cutting south of Fernhurst crossroads 170
6. Blackdown, from near Stagpark Farm. Western closure of Fernhurst anticline and wind gap at Redford, from Older Hill 178
7. Radiolaria from the Mesozoic of Oman 211
8. Photograph of Charlton Sand Pit taken in 1906 218
9. View of the northern face of the Castle Lime Works, South Mimms, showing several sheet pipes. The buttress on the right, which is now hidden behind tip, consists of a vertical pipe of light coloured sand, almost indistinguishable in the Plate, from chalk 219
10. A. The intricate veining of the chalk by Tertiary sand and clay, 60 feet below the general Chalk-Tertiary Junction
    B. Blocks of chalk of varying size and angularity set in dark coloured sand and clay. Both photographs show parts of the side of the trial hole, 60 feet below the general Chalk-Tertiary Junction, in the Castle Lime Works, South Mimms 221
11. A. Tubular chalk stacks near Sheringham
    B. Tubular chalk stack 226
12. A. Lithified crust of chalk
    B. Tubular stack on the foreshore between Sheringham and West Runton 233
13. Successive Stages in the Formation of " Gulls " in the Great Oolite Limestone of Simmonds Quarry, Burleigh, Glos. 250
14. Lower Albian Ammonites from Folkestone, Kent, and Chalvington, Sussex 296

DATES OF ISSUE

VOLUME 61 (1950)

Part 1.	pp. 1–120	31st March, 1950
„ 2.	pp. 121–164	30th June, 1950
„ 3.	pp. 165–218	30th September, 1950
„ 4.	pp. 219–306	29th December, 1950

Proceedings of the
GEOLOGISTS' ASSOCIATION

THE STORY OF QUARTZ CRYSTALS

By E. ERNEST S. BROWN, M.B.E., F.G.S.

(*Presidential Address read 10th March, 1950*)

CONTENTS

		PAGE
1.	EARLY HISTORY	1
2.	MODERN USES AND RECENT DEMANDS	2
3.	CRYSTAL DEFECTS AND METHODS OF EXAMINATION	3
4.	MODE OF OCCURRENCE	5
5.	" IRREGULAR " QUARTZ	6
6.	AGE OF THE QUARTZ DEPOSITS OF BRAZIL	7
7.	WHY ARE BRAZILIAN SOURCES UNIQUE ?	7
8.	OTHER SOURCES OF SUPPLY	8
9.	MINING METHODS AND POTENTIAL RESERVES	9
10.	CONCLUSION	10
11.	REFERENCES...	10
	POSTSCRIPT TO THE PRESIDENTIAL ADDRESS, 1949	12

SUMMARY.—The history of the use of clear quartz is reviewed from early times to its modern use in industry by reason of its piezo-electrical properties. Crystal defects and the examination of raw material, mode of occurrence, *in situ* and derived, are described. The age of the quartz deposits of Brazil is discussed. Why are Brazilian sources unique ? Other sources of supply, mining methods and potential reserves are considered.

1. EARLY HISTORY

THE beauty of clear quartz was appreciated from the earliest times. A necklace of quartz beads has been dated about 5000 B.C. and the Sumerians developed the art of cutting and polishing quartz as seals, beads and jewellery. The Egyptians were adepts in its use as ornaments and the Greeks obtained crystals from the vicinity of Mount Olympus. The very name " crystal " is attributed to the Greek's name for quartz, i.e., Krustallos, literally ice. A somewhat fanciful explanation of their choice of this name is that they believed it to be water so frozen by the gods as to be for ever solid. Later clear quartz or rock crystal was an object of barter by the Phoenicians [**14***].

The production of clear crystal balls is assigned first to oriental lapidaries and these balls have been found in the tombs of Egyptian, Frankish and Saxon kings. From at least medieval times to the present day, crystal balls have been in demand by the devotees and charlatans of crystal gazing. It was the orientals who carried the art of cutting rock crystal to the highest level of skill and intricate design. There are in museums and private collections many exquisite examples of vases, figures, birds and animals dating from the sixteenth and seventeenth centuries. The vases are often embellished with delicate pictorial scenes cut in the quartz ; work which must have called for almost incredible skill and patience and the life-time of many an artisan.

---

* For list of References see page 10.

In the old world, crystals of sufficient size and clarity must always have been rare and their source is speculative. Nests of good crystals are found occasionally in Switzerland and the Chinese imported crystals from the jade and ruby mines of Burma.

2. MODERN USES AND RECENT DEMANDS

Whilst clear quartz was long valued as material for jewellery and ornaments on account of its hardness and brilliance when polished, its first utilitarian application appears to have been for the making of " pebble " spectacles, extended later to its use in optical instruments. The demand for these purposes gave rise to the first exports from Brazil, where water-worn stones were found in the beds of rivers on the eastern seaboard. Increasing demands induced prospectors to follow up the rivers to their sources in what is now the state of Minas Gerais and, in fact, some maps of last century mark this area as the " Crystal Mountains " [**16**].

In 1881 the Curies [**6**] discovered that certain crystals, particularly quartz and tourmaline, exhibited the phenomenon of piezoelectricity. This effect is that, if such a crystal is subjected to mechanical pressure in the direction of any one of its digonal axes, electrical charges are developed at the extremities of those axes and, conversely, that the crystal expands and contracts if subjected to the application of an electrical field. With an alternating voltage the crystal is set into mechanical vibration. These discoveries remained little more than laboratory curiosities until 1917 when Langevin [**12**] applied them to the transmission of ultrasonic waves under water. In 1921 Cady [**4**] showed that properly cut quartz plates could be used to control vacuum tube oscillators and, thenceforward, technical research developed the use of the quartz oscillator plate, whereby the frequency of radio transmission and reception is stabilised and precisely controlled.

There is an immense technical literature on the fabrication and use of quartz plates for radio, and many other present-day and potential applications in telecommunications and other industries. Great advances have been made in the methods of cutting and lapping the plates, in their testing and adjustment and in the precision engineering of their " holders " [**3** and **8**]. Many of these processes were expanded during the war into vast assemblies of mass production. This brief and inadequate reference to the technical side of my subject must suffice to explain how rapidly the demand for the raw material increased between the two wars and eventually established quartz crystals as a strategic mineral of great importance.

The overwhelming bulk of the world's demand for quartz crystals was and is obtained from Brazil. With the first industrial applications of the piezo-electric properties of quartz, the demand for large well-formed crystals became insistent and extensive prospecting and mining for quartz *in situ* developed in Brazil. Long before the last war agents had been established in London, Paris, New York and other capitals and their imports from Brazil were selected by visual inspection. With some fluctuations, the total exports from that country gradually rose from 12 metric tons in 1918 to 747 metric tons in 1938. Ample supplies were available for industrial needs and most cutting laboratories restricted their selections to crystals of good shape, fair size and free from the obvious defects that could be detected visually by experienced technicians.

The immense demands by the Allied Nations in the period 1939–45 far exceeded all possible supplies of large faceted crystals. Fortunately, with improved techniques, industry was able to use, in addition, small crystals, water-worn and irregular (unfaced) quartz. With this extension of range and types, Brazilian exports in 1943 reached a peak of 2411 metric tons, representing 42.3 per cent of the total value of mineral exports that year. It is difficult to convey the significance of these figures in relation to the mining effort involved. On good evidence and from the careful estimates of those in the best position to make them, the ratio of mine-clear quartz to the total quantity of material excavated, was estimated to be 1 : 10,000 for the best mines [**10**]. Further, after examination and trimming, only one half of the mine-clear quartz was suitable for export. The great spoil-heaps left at the mines, and export prices rising to £10–£20 per kilogram, support these conclusions. Obviously, cheap labour and high prices are essential factors for economic production in any country when mine winnings are of that order.

3. CRYSTAL DEFECTS AND METHODS OF EXAMINATION

What then are the defects which necessitate an overwhelming proportion of the crystals mined being rejected because they are useless for fabrication ? First, there are the obvious faults such as irregular growth, cracks, flaws, intergrowths and inclusions of other minerals. These may be rejected on visual examination in strong artificial light or preferably in sunshine. Also at this stage it is often possible to detect electrical twinning (Dauphiné Law) by means of natural etching of the prism faces.

More subtle defects are discovered by examination in a tank filled with oil having a refractory index near to that of quartz. The beam of a strong arc lamp is focused to a central point in the tank and when the crystal is immersed and moved through the beam of light many other defects may be found, particularly bubbles, ghosts or phantoms and " blue needles." The bubbles may occur widely scattered and of fair size or as clouds of tiny vacuoles crossing the crystal in various directions, giving a " milky way " effect. Of great rarity is a large movable bubble, situated a little below the surface of the crystal, which will move freely along for an inch or so when the crystal is tilted (B. M. Collection specimen No. 1947, 24).

Ghosts or phantoms are the reproduction of the crystal faces within the main crystal and they may occur singly or as a series of diminishing sizes. Their faint outlines are made visible by concentrations of tiny bubbles, by slight colour changes or even by thin partings of clay minerals. They seem to represent pauses in the growth of the crystal. The Brazilian technicians call them *egrejas*, which has often puzzled the translator. It is the Portuguese word for " church " and its adoption is due to the outline of the phantom with its pyramidal top having the appearance of a church steeple.

" Blue needles," sometimes known as feathers, are faint lines which may be long and thin or short and thick but the two types do not generally occur together. They may occur in long bundles, in radiating masses, singly or in scattered formations or crowded throughout the crystal. In the arc beam they show up as faintly blue in colour, sometimes only when the crystal is orientated in a particular direction. The thin ones are often glistening and are called " hard " and the short broad forms, of a matt appearance, are called " soft." They have been described as attenuated bubbles and they seem to be hollow. No evidence of any included material has been found. So far as I am aware, appeals to the physicists for an explanation have never resulted in more than the suggestion that they represent " strains in the atomic lattice." In the past, controversy has raged as to whether " blue needles " are a serious defect in an oscillator plate and they may have been blamed for faults not due to the crystal at all. More recently they have been regarded as harmless except perhaps for oscillators required for the highest frequencies.

Optical twinning (Brazil Law), sometimes indicated by naturally etched triangles on the prism faces, is determined by examination of the crystal in polarised light. This is effected in the same oil-bath by passing a strong beam of polarised light through the long, or Z axis of the crystal and so reflecting on a ground glass plate the characteristic triangular patterns of this form of twinning.

The commonest mineral inclusion is tourmaline, in the form of long, thin, black needles. Other common inclusions are rutile, chlorite, calcite and oxides of iron and manganese. There are also many rarities. The rutile occurs as needles and a unique specimen (B. M. Collection No. 1947, 20) is a bundle of closely packed needles partially embedded in a crystal, with minute crystals of pyrite attached to the free ends of the needles. This is illustrated by a drawing in a paper by Johnston and Butler [**10**, p. 614], and was known by my staff in Rio as the " shaving brush "—an appropriate description.

The same examination is applied to clear quartz which lacks crystal faces but this is a little more difficult because natural etching is absent and, before the extent of optical twinning can be seen, it is, of course, necessary to determine the crystallographic axes. With encrusted and abraded specimens, windows must be chipped out at opposite ends to enable the interior to be explored in the light beams.

Brazilian export laws provide for crystals to be classified in 12 grades according to size and four qualities based on the estimated percentage of usable quartz. By using the methods described, experienced inspectors can make close approximations to the " usability percentage " of each crystal, which is the factor controlling the price.

4. MODE OF OCCURRENCE

Wherever massive quartz veins have penetrated rock formations, cavities—vugs of the mineralogist—may occasionally be found within such veins or between them and the country rock through which they have intruded. These vugs tend to be filled, completely or in part, by secondary minerals and particularly by well-formed quartz crystals. It is considered that the crystals were developed from dilute aqueous solutions, as a hydro-thermal process at fairly low temperature, and that the infilling was the end stage of the igneous activity which intruded the main veins. Similarly, mineral-filled vugs may occur in coarse pegmatites. It is owing to the space available that the crystals of quartz and other minerals were able to develop as well-formed crystals, growing inwards from the walls of the vug, sometimes with their apices interlocking but often with room for the crystals to adjust their growth one to the other. It is under these conditions that quartz crystals, based on the milky quartz of the vein, may develop for as much as two-thirds of their length, clear quartz, free from inclusions and other defects and with perfect prism and pyramid faces.

In Brazil such quartz injections are found, as elsewhere, following the line of least resistance and they occur between bedding planes, as lenses in the convex part of folded strata, along joint planes, lines of fault or shear and very frequently at the contacts of granitic intrusions with the metamorphosed country rock. The intrusions may form simple veins, composite lodes, pipes and stockworks. The vugs vary greatly in shape and size from the simple spherical cavity filled by a nest of crystals, to long, meandering, narrow openings along a vein, filled with comb quartz (interlocking crystals). Replacement appears to be rare but there are records of an original vug having been enlarged by solution before its final filling and of replacement of wall-rock by the growth of crystals outwards from the vein [**10**, p. 627].

Many sketches of complex intrusions, ribbon and comb quartz and of unusual vugs are given by Johnston and Butler [**10**].

5. "IRREGULAR" QUARTZ

The foregoing summary of the conditions determining the formation of quartz crystals relates only to their development *in situ*. There remains the type known in industry and commerce as "irregular." This is a varied group, including clear quartz without fully developed faces, crystals from which the faces have been removed accidently in mining, or deliberately by trimming—sometimes to hide defects disclosed by natural etching—and a series ranging from slightly abraded crystals to completely rounded pebbles. For the latter the geologist has more precise definitions, based on occurrence and history after the removal of the crystals from their original setting.

Rock formations subjected to tropical weathering are often completely decomposed to depths of over 50 feet from the surface. The chemical breakdown of igneous and associated rocks results in masses of red clay that may contain boulders of rotten granite and gneiss but in which the quartz survives as the only hard material. The crystals themselves have not, however, entirely withstood the effects of chemical attack because normally their faces are lost. Their surfaces may be deeply etched or they may have acquired a thick cemented skin of limonite or other secondary minerals. Such residual material is known as an elluvial deposit and its presence, as quartz boulders on the surface, is to the prospector an important indicator of crystal-bearing rocks beneath the zone of weathering.

The soft weathered material is readily removed by denudation and so the next stage in the history of the residual quartz is its condition when found as colluvial deposits in hill-creep, plastered on the valley sides and as screes abutting on escarpment faces. The crystals have, of course, been further abraded and have reached a further stage towards complete rounding. Under favourable conditions and by reason of differential sorting, colluvial deposits should yield a larger ratio of quartz to the total material excavated than in the case of elluvial material.

The final stage is that of alluvial deposits as river gravels, where the crystals are now completely rounded and range from large boulders to a pebble grade. This material is to some extent a concentrate and, as survivors after long periods of torrent battering, the stones are freer from major cracks and flaws.

6. AGE OF THE QUARTZ DEPOSITS IN BRAZIL

All the quartz occurrences in Brazil are emplaced in the great massif of Pre-Cambrian rocks or in adjacent metamorphosed Palaeozoic formations. No occurrences are known in post-Silurian rocks. Johnston and Butler [**10**] consider that the emplacement possibly occurred in late Silurian or early Devonian times—a period recognised as a metallogenetic interval in Brazil.

The problem is affected by the metamorphism of the sediments in question and some formations at present considered to be Palaeozoic in age may prove to be Pre-Cambrian, though younger than the rocks of the massif. For example, Campbell [**5**, p. 776] records that schistose rocks in Goiaz, formerly regarded as Cretaceous in age, are now considered to be Algonkian.

Age determination of radioactive minerals from associated pegmatites in Minas Gerais, falls into two groups, i.e., Ordovician and Early Cambrian respectively [**10**].

7. WHY ARE BRAZILIAN SOURCES UNIQUE?

Innumerable quartz veins are common in granitic and kindred acid rocks and in metamorphic and older sedimentaries, on a world-wide scale. Pegmatites are also common and widely dispersed. Hence single crystals of clear quartz, up to a few inches in length, and pretty little nests of such crystals are the commonest objects of mineral collections everywhere. It should be noted, however, that such crystals generally exhibit either or both optical and electrical twinning.

It is a fascinating problem why in Brazil alone large well-formed crystals occur in immense quantities, that crystals weighing up to 10 metric tons are not uncommon in some districts [**10**] and that throughout the whole range of sizes a small proportion is free from either form of twinning.

The bulk of quartz crystals found in Brazil occur in three of the central states, i.e., Minas Gerais, Bahia and Goiaz. All three areas are parts of the great central massif of Brazil, which is formed of ancient Pre-Cambrian rocks, overlain by the denuded remains of great thicknesses of Palaeozoic sediments, metamorphosed to a varied series of schists and quartzites and subjected to intensive and large-scale granitisation.

To be frankly speculative, it seems that three criteria probably most important for the formation of large crystals of high quality were present in the Brazilian massif to an extreme degree unexampled, so far as is known, elsewhere. These criteria may be summarised as follows :

(1) a vast excess of aqueous siliceous solutions arising from a magma of exceptional acidity,
(2) a thick blanket of overlying rocks which retarded cooling,
(3) the whole emplacement occurring in the heart of one of the most stable blocks of the earth's crust.

In so far as these conditions were approached in other parts of the world, crystals of moderate size and clarity occur, but Brazil may be unique as regards the maximum occurrence *in triple conjunction* of the requirements suggested.

8. OTHER SOURCES OF SUPPLY

In 1937 I undertook an investigation of possible supplies of crystals from Empire sources. Obviously the first task was to learn the conditions in which the crystals occurred in Brazil but, with one exception [**16** and **17**], the available literature yielded little definite information. It did appear, however, that the major occurrences were associated with the ancient massif of Brazil, where it had been penetrated on a large scale by acid magma, developing exceptionally large quartz veins and pegmatites, which passed into overlying or adjacent metamorphosed sediments. The crystals occurred in cavities in these intrusions and particularly at the junction of the massif and the metamorphosed series.

I enlisted the assistance of many of our Dominion and Colonial geologists and here I pay tribute to their most helpful and ready co-operation in the investigation. Their first-hand knowledge of areas which at all simulated the Brazilian conditions was invaluable and, restricted only by the smallness of their staffs and later by war-time conditions, much information was assembled. Many samples were sent by my correspondents but, with few exceptions, they were too small for economic use or were hopelessly twinned or flawed.

One amusing episode enlivened the correspondence. With the exports of jade from Burma to China occasional large quartz crystals were sent because their unusual form had a special appeal to the importers. This form, which has not been seen well-developed elsewhere, was peculiar in that the pyramid faces overlapped the prism faces in a series of steps, or more strictly a number of pyramids had developed successively, each larger than the supporting prism. Such forms were known as " pagoda stones " from their resemblance to that type of architecture and they were regarded by the Chinese with veneration, finding a home in their temples. It was my business, therefore, to seek more information about their origin in the hope of securing large crystals of normal type, free from sacred peculiarities. Through the good offices of the Geological Survey in Rangoon, I was put in touch with a native Inspector of Mines in the area concerned. He was unable to produce what I wanted and samples were unsatisfactory but, as the correspondence extended, rumours arose that an old Chinaman near Mogok knew of wonderful, large, single crystals that had been found long ago. Alas, they were buried with his ancestors, who could not be disturbed ! Further pressure as to where they came from failed to produce crystals or concrete information but later came the news that, after all, to oblige so persistent an inquirer, perhaps the Chinaman's ancestors would not object too much to disturbance if it were for the financial benefit of their descendant. As the price demanded for the buried treasures was at least three times the market value of the best tested crystals, so far as I was concerned, the ancestors were left in peace.

On the whole the results of the investigation were disappointing, although from time to time there were hopes of securing supplies from new areas. Quantities of water-worn crystals were found in Uganda [**18**] but their source was not discovered. It may well be that these alluvial deposits were the relics of more than one cycle of denudation. Extensive search in Kenya and many other areas proved abortive or yielded such small quantities that any mining operations would have been entirely uneconomic. The failure to appreciate the probable proportions of usable quartz to total mine production, as experienced in Brazil, may be the reason why some supplies have not been forthcoming from small-scale prospecting in the areas investigated.

Whilst the American geologists discovered a small supply in Arkansas [**7**], the French met their pre-war needs from Madagascar [**11**], and small supplies were obtained from the wolfram mines of Tasmania, Brazil remains the only major source of supply of the type of crystals required by industry.

9. MINING METHODS AND POTENTIAL RESERVES

Brazilian supplies, for the most part, have always been obtained by single miners or small groups, working small prospects and shallow pits. When demand and prices fall they drift away to other mining ventures but return as soon as prices are attractive. The introduction of heavy mining machinery during the war contributed to the unprecedented production but, in normal times, the older methods will meet all likely demands and the use of machinery for economic mining may be restricted to bulldozers for removing heavy over-burden and to pumping gear.

The potential reserves of quartz crystals in Brazil are very great. Undoubtedly war-time production diminished visible reserves in Minas Gerais and Bahia but few mines were worked to a greater depth than 30 metres and large areas are still geologically unexplored. In 1944 important new districts were discovered and developed in north-west Goiaz and here is a vast area awaiting intensive prospecting, with probable extensions northwards into Para.

The three types of residual quartz already described have yielded large quantities of usable crystal from Brazil but, as these types grade one into the other, it is impossible to assess their relative importance. Such deposits occur elsewhere, as in Uganda. They may be the residue of more than one cycle of denudation and may occur in areas where the original source rocks have long since been removed. If increased demands ever again create a shortage of faceted crystals, the supply of the " irregulars " of commerce may safely be regarded as inexhaustible.

10. CONCLUSION

This brief account of the story of quartz crystals is far from being exhaustive but I have tried to summarise material which is widely scattered in geological and technical literature. Save for a few speculations of my own, no information is given which has not been published in far greater detail elsewhere.

Since my return from Brazil in 1946, I have found that the extent of the quartz deposits of that country was not well known here and that the importance of quartz crystals in industry and, therefore, in war-time as a strategic mineral, was not generally recognised. With the increasing recognition of the importance of our Geological Surveys overseas and, it is to be hoped, their consequent enlargement, there is still the possibility that valuable sources of supply of high quality quartz crystals may yet be found within the British Empire.

11. REFERENCES

1. Alves de Souza, A. J. 1944. Industrialização do quartzono Brasil, *Mineração e Metalurgia*, 8, pp. 200–4.
2. Booth, C. F. and E. J. C. Dixon. 1935. Crystal Oscillators for Radio Transmitters. *Journ. Instn. Elect. Engrs.*, 77, pp. 197–244.
3. ——— and C. F. Sayers. 1939. The Production of Quartz Resonators, etc. *P.O. Elect. Engrs. Journ.*, 31, pt. 4, 32, pts. 1 and 2.
4. Cady, W. G. 1922. The Piezo-electric Oscillator. *Proc. Inst. Rad. Engrs.*, 10, pp. 83–114.
5. Campbell, D. F. 1946. Quartz Crystal Deposits in the State of Goiaz, Brazil, *Economic Geology*, 41, No. 8.
6. Curie, P. and J. Curie. 1880–9. Numerous papers in *Comptes Rendus Acad. Sci.*, Paris, vols. 91–3 (see Vigoureux, p. 125).
7. Engel, A. E. J. 1946. The Quartz Crystal Deposits of Western Arkansas, *Economic Geology*, 41, No. 6.
8. Frondel and Others. 1945. Symposium on Quartz Oscillator Plates. *Amer. Mineralogist*, 30, Nos. 5 and 6.
9. Imperial Institute. 1938. Piezo-electric Quartz. *Bull. Imp. Inst.*, 36, pp. 185–96.

10. Johnston, W. D., Jr. and R. D. Butler. 1946. Quartz in Brazil. *Bull. Geol. Soc. Amer.*, 57, pp. 601–50.
11. Lacroix, A. 1922. *Mineralogie de Madagascar*. Paris.
12. Langevin, P. 1928. Les ondes ultrasonores. *Rev. Gen. Elect.*, 23, p. 626.
13. Oliveira, A. I. and O. H. Leonardos. 1943. *Geologia do Brasil*, 2nd Ed.
14. Strong, H. T. (no date). *Krustallos—A Story of Quartz.* Treatise published by the Miller Laboratories. U.S.A.
15. Vigoureux, P. 1939. *Quartz Oscillators and their Applications.* H.M. Stationery Office, London.
16. Walls, R. R. 1919. The Rock Crystal of Brazil. *Optical Soc. Trans.*, 21, No. 4.
17. ———. 1929. Rock Crystal and Diamond Pipes in Brazil. *Geol. Mag.*, 66, pp. 111–16.
18. Wayland, E. J. 1938. *Notes on Rock Crystals.* Geol. Surv. of Uganda, Bull. No. 3.

There is a useful glossary of terms in **8**, pp. 461–8.
References **8**, **9**, **10** and **15** provide extensive bibliographies.
References **3**, **5**, **8**, **9**, **10** and **15** are well-illustrated by photographs and drawings of crystals and of laboratory and mining operations.

POSTSCRIPT TO THE PRESIDENTIAL ADDRESS, 1949

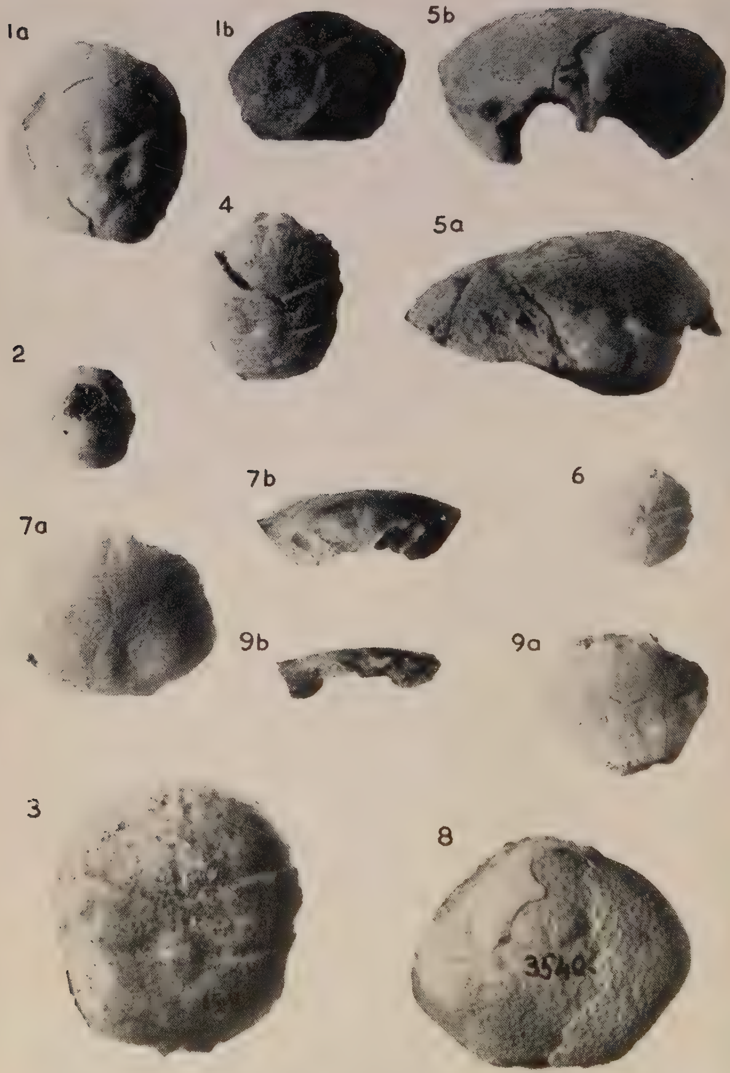
To complete my admonitions of a year ago respecting field work perhaps I may add the following :

1. Mr. W. E. Howarth kindly called my attention to the need for a word of warning when collecting in the field, which I think applies particularly to a party. A call to move on from a collecting site comes before the collector is ready or has packed his specimens. At the next stop, or more probably at lunch time in another quarry, he may discard some specimens from a previous site. Another time, another collector picks up the discards. The result may obviously be serious when a record is published of specimens found at the second site.

2. The late Professor Watts used to warn parties of the serious consequences that may arise if glassy rocks such as rhyolites, obsidian, etc., are trimmed elsewhere than in the quarry. The knife-edged chips, falling on pasturage or in wayside grass, may cause injuries to browsing cattle or sheep.

3. Then there are always gates to shut and the tops of walls to replace.

We want to retain the goodwill of farmers and landowners. Once a party of this Association was harried from its chosen luncheon place by an irate Irishwoman. It appeared that a former party had left a comb in the grass. Her only cow had swallowed the comb and had died from the effects thereof.



DROMIACEAN CRABS FROM THE ENGLISH CRETACEOUS

[*To face p.* 13.

SOME DROMIACEAN CRABS FROM THE ENGLISH CRETACEOUS

By C. W. and E. V. WRIGHT

[*Received 7th April,* 1949]

SUMMARY—The Dromiacean genera *Plagiophthalmus* Bell, *Goniodromites* Reuss and *Cyphonotus* Bell are discussed and new species of each are described from the English Albian and Cenomanian ; the type species of *Plagiophthalmus* and *Cyphonotus* are also redescribed and figured. The phylogenetic position of *Cyphonotus* and related Dynomenidae is examined.

THE nucleus of this paper is a description of certain crabs found in the Lower Albian Shenley Limestone of Leighton Buzzard. We have found occasional specimens over a period of years but the majority of our specimens came from a single lenticle of limestone discovered *in situ* in Munday's Hill Pit on Shenley Hill in 1944.

To the description of the Shenley Limestone species we have added that of some other new forms and have considered the range and phylogeny of the genera to which these species belong.

Sub-order	:	Brachyura
Tribe	:	Dromiacea
Sub-tribe	:	Dromiidea
Family	:	Prosoponidae H. von Meyer
Sub-family	:	Pithonotinae Glaessner

Members of this sub-family differ from the Prosopinae by having a definite lateral edge to the carapace, a not very prominent rostrum which is either bilobed or triangular, the cervical furrow as strong as or stronger than the branchiocardiac, no hepatic furrow and only slight sculpture on the carapace (after Glaessner, 1933b, p. 180).*

GENUS : *PLAGIOPHTHALMUS* BELL 1863

The only British form of Pithonotinae so far described from the Cretaceous is *Plagiophthalmus oviformis* Bell from the Cenomanian of south-west England. As long ago as 1898 Carter (p. 21) recognised that this species showed considerable resemblance to *Pithonoton* von Meyer, typically an Upper Jurassic genus. Beurlen (1928, p. 149) was of the opinion that, while certain Neocomian species should be referred to *Pithonoton*, the genus *Plagiophthalmus* Bell should be retained for the Upper Cretaceous *P. oviformis* Bell and *P. pentagonalis* Segerberg. He thought that the distinction was justified partly by the comparative narrowness of the posterior margin of *Plagiophthalmus* and partly by the difference in geological horizon. The latter factor however should not be given too much weight in a group like the Brachyura of which comparatively few fossil forms are known and of which many genera have long ranges.

---

* For list of References see p. 26.

Van Straelen (1928, p. 614) stated that *Plagiophthalmus* Bell differs from *Pithonoton* von Meyer by the more oval form of the carapace, but added that in this feature there was some resemblance to Jurassic species placed in the subgenus *Cycloprosopon* of *Pithonoton*, regarded by Glaessner (1933, p. 181) as in part synonymous with *Goniodromites* Reuss. This remark of Van Straelen's takes on an added interest now that we know of two English Cretaceous species of *Goniodromites* (see below), a genus hitherto recorded only from the Jurassic. The question arises whether *Plagiophthalmus* Bell should be regarded as derived from, if not synonymous with, *Pithonoton* or *Goniodromites*.

Carter (1898, p. 21) correctly pointed out that *Plagiophthalmus oviformis* Bell is not quite such a featureless form as the type figures might suggest. It has in fact slight orbital and lateral spines, admittedly more noticeable in internal casts that in specimens with the test preserved. These are features suggesting connection with *Goniodromites* rather than *Pithonoton*. One of the essential distinguishing features between the two genera is, according to Glaessner (1933b, pp. 180, 181), the presence in *Pithonoton* and absence in *Goniodromites* of a hepatic lobe below the anterior part of the lateral margin. There is an indistinct indication of such a lobe in *Plagiophthalmus*, but the sulcus that should define it is incomplete. There is, moreover, no trace of the definite hollows in the margin for the last pair of legs, which characterise *Pithonoton*, and *Plagiophthalmus* should probably therefore be regarded as derived from *Goniodromites*.

A diagnosis of *Plagiophthalmus* may be given as follows :—Prosoponid, sub-family Pithonotinae. Carapace rather elongated and straight sided, much inflated in side and front views. Lateral margins very distinct, smooth or spinose. Cervical and branchiocardiac furrows fairly prominent and of about equal depth and width. Rostrum turned down in front and broadly bilobed. No distinct hollows for the last pereiopods. Eye-sockets wide and deeply sunk. A faint indication only of a hepatic lobe below the antero-lateral margin. Surface of the carapace smooth or finely pitted.

PLAGIOPHTHALMUS OVIFORMIS Bell

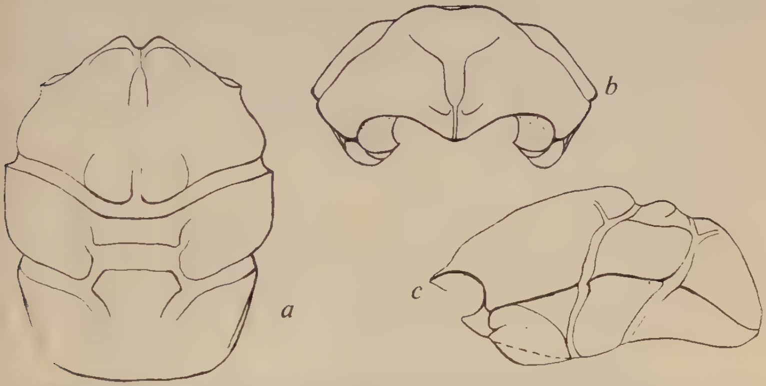
Plate 1, Fig. 1a, b, text Fig. 1a–c

1863 *Plagiophthalmus oviformis* Bell, "Fossil Malacostracous Crustacea," *Palaeont. Soc.*, Pt. 2, p. 9, Plate ii, Figs, 1–3

1898 *Plagiophthalmus oviformis* Carter, "Contribution to the Palaeontology of the Decapod Crustacea of England," *Quart. Journ. Geol. Soc.*, 54, p. 21

non 1875 *Prosopon oviformis* de Tribolet, "Description des Crustacés décapodes des étages néocomien et urgonien de la Haute Marne," *Bull. Soc. Géol. France*, ser. 3, t.3, p. 457, Plate xv, Fig 10.

Since Bell's figures are not particularly clear, we have included for purposes of comparison diagrammatic drawings (Fig. 1) of a typical internal cast and photographs of a specimen showing the frontal margin.



1.* *Plagiophthalmus oviformis* Bell. (a) top (b) front and (c) side views of an internal cast from the Cenomanian of Wilmington, Devon. × 2. Authors' Collection No. 19122. In (c) the area below the broken line is restored from the other side of the specimen.

PLAGIOPHTHALMUS NITONENSIS sp. nov.

Plate 1, Fig. 2, text Fig. 2a, b.

Type. The holotype, and only known specimen, is No. 10152 in the authors' collection.

Description. The holotype consists of a carapace with much of the test preserved, but the metagastric region and surrounding parts are missing. It has a length of 14 mm. and a breadth of 11.5 mm. It has not been possible to expose more than the upper side of the carapace as the matrix, a phosphatic nodule, is too hard.

Apart from the projecting front part the carapace is roughly rectangular in outline, the lateral margins being nearly parallel. They turn sharply inwards at the rear to form the distinct posterior margin. The carapace is strongly inflated in both side and front views.

Only the outer parts of the cervical furrow are preserved; they show that it is narrow and moderately deep. The branchiocardiac furrow has about the same dimensions and is nearly parallel to the cervical. A slight furrow divides the frontal region and separates the two epigastric lobes. As stated above the metagastric area is missing in the type. There are only two tubercles visible on the rather insignificant cardiac region. Apart from the two main transverse furrows the carapace is only slightly differentiated.

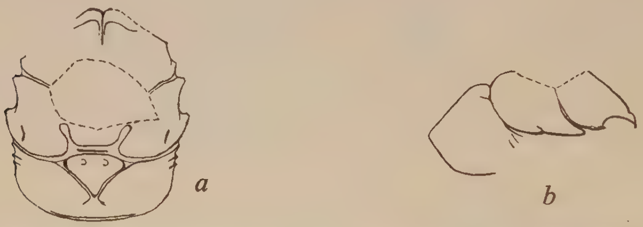
---

* Minor surface ornament is omitted in all text figures except fig. 6.

The most prominent feature is the presence of two strong, almost cylindrical, spines on each side projecting obliquely forward between the ends of the cervical and branchiocardiac furrows. There are two slighter spines between the cervical furrow and the orbits and three, still smaller, on the margin behind the branchiocardiac furrow.

The eye sockets are large and set widely apart, almost on the outer angles of the carapace.

The surface of the test is smooth except for numerous fine pinhole pits.



2. ***Plagiophthalmus nitonensis*** sp. nov. (a) top and (b) side views of the holotype from the Lower Albian Carstone of Reeth Bay, Isle of Wight. × 2. Authors' Collection No. 10152.

Affinities and differences. The present species differs from species of *Goniodromites*, with which it might be confused, in the nearly parallel sides of the carapace, the strong inflation and the lack of granulation of the test. In all these characters *P. nitonensis* approaches *P. oviformis* Bell, from which it is distinguished by its more rectangular outline, broader posterior margin and less strongly arched profile, but above all by the strongly spinose lateral margins.

Horizon and locality. P. nitonensis was found in a phosphatic nodule on the beach in Reeth Bay, near Niton, Isle of Wight, derived from the Carstone in the cliff. The horizon is thought to be the lower part of the *Douvilleiceras mammillatum* zone of the Lower Albian. The associated crustacea are *Homarus longimanus* (G. B. Sow.) and an unidentified brachyuran represented only by strongly ornamented chelae.

GENUS : *GONIODROMITES* REUSS 1859

Revised diagnosis. Carapace flat and broad. Cervical furrow stronger than the transverse branchiocardiac. All other furrows faint. Rostrum broad, projecting straight forward or bilobed.

Posterior margin fairly broad ; distinct hollows for the last pereiopods. Lateral margin in front of the branchiocardiac furrow distinctly developed. Eye sockets wide and deeply sunk. No hepatic lobe below the antero-lateral margin (after Glaessner, 1933b, p. 181).

GONIODROMITES SCARABAEUS sp. nov.

Plate 1, Figs. 3, 4, 5a, b, 6, text Figs. 3 to 6.

1903 *Plagiophthalmus* (*Prosopon*) sp. Lamplugh and Walker, " A Fossiliferous Band at the top of the Lower Greensand near Leighton Buzzard," *Quart. Journ. Geol. Soc.*, 59, p. 263.

Types. Holotype G.S.M. No. 88773 (coll. R. V. Melville), paratypes Authors' coll. Nos. 10909, 15837 and 15839.

Material. Besides the types we have examined a number of other specimens in our own collection and that of the Sedgwick Museum, Cambridge (B 24727–32, B 42425–6). Most of the specimens consist of more or less complete internal casts of carapaces with traces of the inner layers of the test, but the holotype and a few others have better preserved tests. Fourteen specimens came from a single lenticle of limestone.

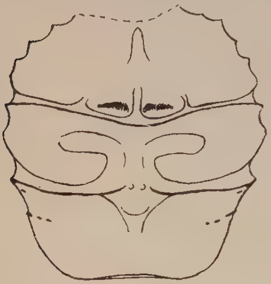
Description :—

		Paratypes		
Dimensions (in millimetres)	Holotype	(10909)	(15837)	(15839)
Length	21	14	20	?18.5
Breadth	18.5	13	?19	17

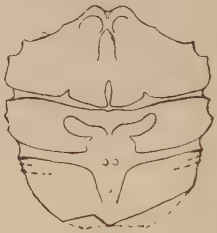
The carapace is slightly longer than broad and is bluntly pentagonal, with the antero-lateral margins converging at an obtuse angle and the postero-lateral converging slightly towards the narrow posterior margin. Viewed from the front the carapace forms a flattened arch and viewed from the side a low curve with the apex a quarter of the way from the front.

The cervical and branchiocardiac furrows, which are of nearly equal prominence, divide the upper surface into three roughly equal parts. The cervical furrow is deep and curves slightly backwards in the middle. The branchiocardiac runs nearly parallel, at the sides, to the cervical furrow.

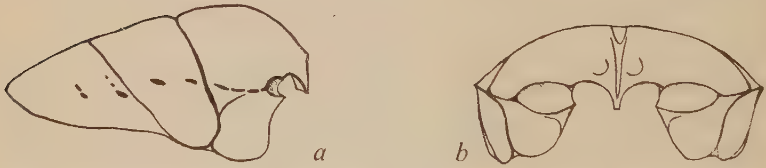
Viewed from above the frontal region is broadly bilobate, and from in front there is a narrow downward projection between the eye sockets. The slightly tumid epigastric lobes are divided in front by a shallow furrow and behind by the narrow anterior part of the metagastric lobe. This is fairly well defined on the test but its sides are not so clear on the internal casts ; a slight longitudinal furrow divides it in the rear. A wide short urogastric lobe is bounded behind by a slight straight transverse furrow separating it from the pentagonal cardiac region, which has three tubercles set in a triangle, generally present throughout the family. The extent to which the various regions can be distinguished varies somewhat in different specimens.



3. *Goniodromites scarabaeus* sp. nov. Top view of a paratype internal cast from a Lower Albian Shenley Limestone lenticle, Munday's Hill Pit, Shenley Hill, Leighton Buzzard. × 2. Authors' Collection No. 15839.



4. *Goniodromites scarabaeus* sp. nov. Top view of a paratype internal cast from Shenley Limestone, Munday's Hill Pit. × 2. Authors' Collection No. 10909.



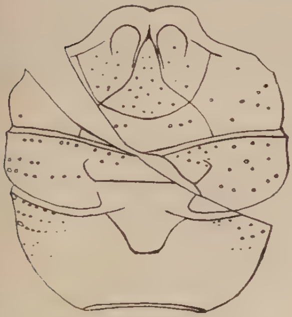
5. *Goniodromites scarabaeus* sp. nov. (a) side and (b) front views of a paratype internal cast, from Shenley Limestone, Munday's Hill Pit. × 2. Authors' Collection No. 15837.

The whole upper surface except for the frontal and orbital regions and the area just above the antero-lateral margins is ornamented with distinct small sparse granules. On the branchial regions they tend to collect in rows parallel with the transverse furrows, especially on the posterior edge of the two furrows.

The lateral margins of the holotype show slight spines behind the orbits and immediately behind the ends of the cervical and branchiocardiac furrows, and between these spines slight rounded bulges. In the two paratypes, and in most of the internal casts, the spines are much more definite, though varying in number. Usually there are two or three spines between the orbit and the end of the cervical furrow, two between this and the branchiocardiac and one immediately behind the latter. However, in paratype No. 10909 there are three between the two furrows on the left side and only two on the right (see Fig. 4).

The orbits are large and transversely oval. They are moderately deep and are situated well out to the side.

We have seen no trace of the abdominal regions or appendages associated with any of the carapaces, but dissociated fragments of long thin granulated pereiopods occur in the Shenley Limestone and may belong to the present species.



6. *Goniodromites scarabaeus* sp. nov. Top view of holotype from Shenley Limestone, Munday's Hill Pit. × 2. GSM 88773.

Affinities and differences. The general form of *G. scarabaeus* and the arrangement of the regions is closely similar to that of typical Jurassic species of the genus, such as *G. bidentatus* Reuss or *G. globosum* Remeš. The number and form of the lateral spines however is distinct. The differentiation of the epigastric lobes and the outline of the carapace also serve to distinguish the present species. The species of *Plagiophthalmus* are more inflated, have the eye sockets closer together and lack the granulation of *G. scarabaeus.*

Horizon and locality. All the specimens seen have come from the lenticles of Shenley Limestone of the Lower Albian *Leymeriella tardefurcata* zone, occurring in a very restricted area on Shenley Hill, Leighton Buzzard, Bedfordshire (Twenty-one Acre and Munday's Hill Pits).

? *GONIODROMITES* sp.

There is probably a second species of *Goniodromites* from the English Lower Cretaceous but it is unfortunately represented only by one very incomplete specimen. This is part of the carapace, with the inside alone visible, embedded in a chip of very hard limestone, from the Hythe Beds (Upper Aptian, ? *martini* Zone) of Sevenoaks, Kent. It was collected by Mr. S. C. A. Holmes and is G.S.M. No. 88772 in the Geological Survey collection.

Only at the posterior end is any of the margin preserved so that it is impossible to make out the shape of the carapace. It is however clearly comparable with the Albian form just described, differing by being less depressed in both side and end views and by having the regions rather more tumid. It is closely related to *G. scarabaeus* but better material is needed before it can be fully described.

Family : Dynomenidae Ortmann
Genus : *Cyphonotus* Bell 1863

(Synonyms—*Palaeodromites* A. Milne Edwards 1869, *Distefania* Checchia-Rispoli 1917)

Glaessner has already (1933a, p. 584, 5) pointed out that the differences between *Distefania* and *Cyphonotus* mentioned by Checchia-Rispoli were not great enough to justify generic separation. *Palaeodromites* is also clearly a synonym.

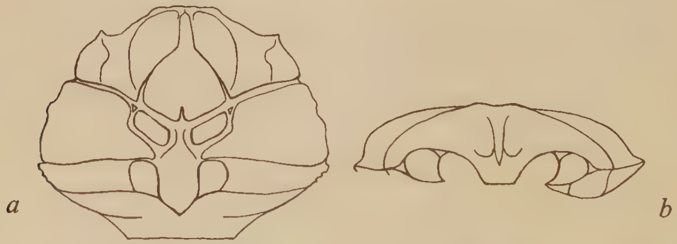
The evolution of *Cyphonotus* and allied genera is discussed below after the description of the English forms.

CYPHONOTUS INCERTUS Bell

Plate 1, Fig. 7a, b, text Figs. 7 to 9.

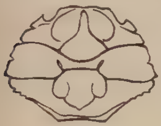
1863 *Cyphonotus incertus* Bell, op. cit., p. 8, Plate i, Figs. 17–19
1896 *Cyphonotus incertus* Bell pars. Carter, op. cit., p. 20
1933 *Cyphonotus incertus* Bell Glaessner, " Neues Krebsreste aus der Kreide " *Jahrb. Preuss. Geol. Landes.*, Bd. 53 (1932), pp. 584–6.
1940 *Cyphonotus incertus* Bell Van Straelen, " Crustacés Décapodes Nouveaux du Crétacique de la Navarre," *Bull. Mus. Roy. Hist. Nat. Belge*, T.20, No. 25.

As Glaessner (1933a) has said, Bell's figure of the upper surface of the Horningsham specimen was bad. We include therefore a diagrammatic sketch (Figs. 7a, 7b) of the lectotype here selected, the original of Bell's Plate I, Figs. 17 and 18, to show the furrows and lobes.



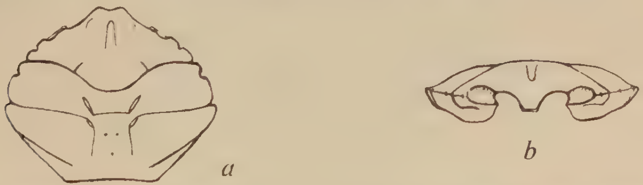
7. *Cyphonotus incertus* Bell. (a) top and (b) front views of holotype from Cenomanian of Horningsham, Wiltshire. × 2. B.M. No. 59524.

It will be seen that there are many features visible which were not shown in Bell's figure. In particular the antero-lateral margin is considerably, though irregularly, indented (as indeed is shown in his figure of the Cambridge Greensand specimen) and the sulci are not quite as shown. There are in fact faint but distinct antennary and hepatic sulci ; the transverse part of the branchiocardiac sulci can just be made out ; and there is a very faint transverse sulcus dividing each posterior branchial lobe. The urogastral lobe is divided longitudinally in the centre. There is on either side of the cardiac region an approximately oval lobe lying between the branchiocardiac and the posterior branchial sulci.



8. *Cyphonotus incertus* Bell. Top view of a specimen from Shenley Limestone, Twenty-one Acre Pit, Shenley Hill, Leighton Buzzard. GSM 8502. Natural size.

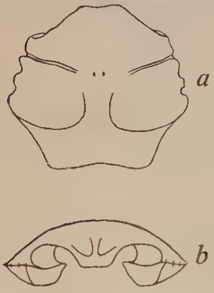
The lectotype is small (19 mm. in greatest breadth) and all these features would not necessarily be present in larger specimens. The larger *Cyphonotus* from the Cambridge Greensand are slightly shorter and broader and slightly less inflated. They have much more distinctly indented margins ; there are two roughly rectangular projections in front of the end of the cervical furrow, two between it and the branchiocardiac and one, succeeded by several small spines, behind the latter. The sulci are generally narrower and rather less distinct than in the small lectotype. The ornament is less prominent and consists of mingled larger and smaller granules ; in some specimens some or all of the larger, in others both large and small, are hollowed out and contain a central papilla. Any surface between the granules is covered with shallow pits.



9. *Cyphonotus incertus* Bell. (a) top and (b) front views of an internal cast from Shenley Limestone, Munday's Hill Pit. Authors' Collection, No. 15833. Natural size.

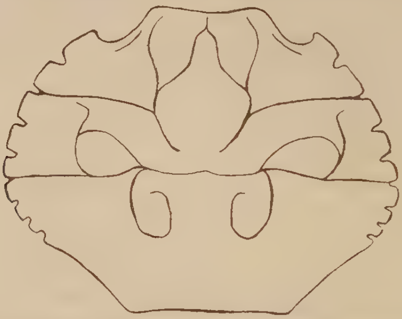
Until we examined the lectotype we considered the specimens from the Shenley Hill Limestone to form a distinct though rather variable species. It is now clear that they cannot properly be separated specifically from *C. incertus* Bell although there are certain differences. One of the Shenley specimens (see Fig. 9) is markedly depressed ; the other two figured are however somewhat less so. The indentations of the margin in all the Shenley specimens are also more marked than in later examples.

C. himerensis (Checchia-Rispoli) (Fig. 11) differs from *C. incertus* Bell in its larger size, less pentagonal outline and more indented margins. The smaller Shenley specimen of *C. incertus* (Fig. 8) however is very close to the Sicilian species, especially in the inclination of the rostrum and the differentiation of the regions. It is however less rounded in outline, it has spinous projections on the postero-lateral border instead of the large rectangular projections of *C. himerensis* and the metagastric lobe does not extend so far back. *C. centrosa* Van Straelen is very closely related to *C. himerensis* and differs in the same characters as does that species from *C. incertus.*



10. *Cyphonotus octodentatus* (A. Milne-Edwards). (a) top and (b) front views after the author's figures of the holotype from the Hauterivian of Auxerre. Natural size.

Of earlier species *C. octodentatus* (A. Milne-Edwards) from the Neocomian of Auxerre (see Fig. 10) differs in being proportionately longer and narrower ; it has less well defined regions and only four projections on each side, compared with the five generally present in *C. incertus* and nine in *C. himerensis*. *C. autissiodorensis* (Van Straelen) (described in 1936 as a *Cyclothyreus*[1]) is a contemporary



11. *Cyphonotus himerensis* (Checchai-Rispoli) after the author's restored and diagrammatic figure of the holotype from the Cenomanian of Himera. Natural size.

---

[1] Although the oval outline of this species recalls *Cyclothyreus strambergensis* Rem̌es, the arrangement of the sulci and lobes of the carapace and the indentations of the antero-lateral margin make it necessary to assign it to *Cyphonotus.*

of *C. octodentatus.* It is a much shorter species and is almost transversely oval in plan view ; apart, however, from the convex postero-lateral margins it is a typical *Cyphonotus.* From it *C. incertus* is distinguished by the straight or concave postero-lateral margins, less rounded antero-lateral margin, narrower posterior border, shallower sulci and rather less differentiated regions.

The Aptian (Urgonian) species ?*C. renevieri* (de Tribolet) differs considerably in shape. Its outline is more nearly square and the orbits much further apart than in any later species of the genus. Moreover the cervical furrow runs straight across the carapace, except for a small bend backwards in the centre, and there is a narrow but distinct longitudinal sulcus, continuing across the branchial regions the line of the sulcus that bounds the mesogastral region.

The type of the Tithonian *C. oxythyreiforme* (Gemmellaro) differs from *C. incertus* in its less angular outline, more curved sulci and less developed branchial regions, with the consequence that the " centre of gravity " of the carapace lies further back. None of these features however is so obvious in the Moravian specimen attributed to this species by Remeš (1895, Plate ii, Fig. 9)

Locality and Horizon. Five specimens have been seen from the limestone lenticles on Shenley Hill, near Leighton Buzzard (Twenty-one Acre and Munday's Hill Pits), belonging to the *Leymeriella regularis* Subzone of the Lower Albian *L. tardefurcata* Zone. It is rather rare in the Upper Albian Cambridge Greensand. The lectotype is the only English Cenomanian specimen that we know. Van Straelen (1936) refers to a French Cenomanian specimen and Glaessner (1933a) to a German example from the top of the Cenomanian ; it is possible that they belong to the new species described below.

CYPHONOTUS INTEGRIMARGINATUS sp. nov.

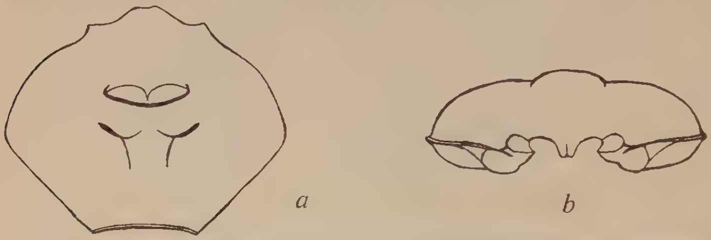
Plate 1, Fig. 8, text Fig. 12a, b.

1898 *Cyphonotus incertus* Bell Carter pars, op. cit., p. 21

Type. The holotype is No. 3450 in the authors' collection.

Description. We originally regarded the figured specimen as merely a slightly unusual example of *C. incertus* Bell but inspection of the types of Bell's species has made it clear that the present form should be given specific distinction. It is relatively broader, shorter and more hexagonal in outline than *C. incertus.* In front view it is slightly more inflated than the lectotype (Bell, Plate I, Figs. 17 and 18) and considerably more so than the syntype (Bell, Plate I, Fig. 19) and other Cambridge Greensand specimens. The regions of the carapace are even less distinct and the cervical sulcus in particular is quite invisible except in the middle. The lateral margin forms a very distinct thickened rim and is entirely smooth and unbroken, in contrast with all other forms of the genus, including typical *C.*

incertus Bell. The orbits are relatively narrower, the distance between the outer edges of the orbits being 43 per cent of the total breadth of the carapace of the present form against 62 per cent in the lectotype and 54 per cent in the syntype of *C. incertus* Bell.



12. *Cyphonotus integrimarginatus* sp. nov. (a) top and (b) front views of the holotype from the Cenomanian of Wilmington, Devon. Authors' Collection No. 3450. Natural size.

The upper surface is ornamented with well-separated distinct granules, mostly with hollowed tops containing a central papilla, as described by Carter in *C. incertus* (1898, p. 21). Between these granules the surface is covered with irregular small shallow pits, distant apart by about their own diameters.

Locality and Horizon. The holotype came from the smaller and more northerly of the two pits in the village of Wilmington in Devon. The horizon is Lower Cenomanian. The associated crustacea are *Plagiophthalmus oviformis* Bell, *Trachynotus sulcatus* Bell, *Necrocarcinus bechei* (Deslongschamps), *N. woodwardii* Bell, *Calappa cranium* Wright and Wright, etc. A similar but damaged specimen in the Sedgwick Museum (B8845), mentioned by Carter as *C. incertus*, is from Chardstock, Devon.

GENUS : *DIAULAX* BELL 1863

DIAULAX CARTERIANA Bell

Plate 1, Fig. 9a, b.

1863 *Diaulax Carteriana* Bell, op. cit., p. 6, Plate i, Figs. 14–16

This species is one of the characteristic crabs of the Cambridge Greensand and has also been found rather rarely in the Folkestone Gault. Bell's figure, of a rather worn specimen, suggests a form differing considerably from specimens of the genus from the Shenley Limestone. Examination of better preserved Cambridge Greensand specimens however shows that there are no grounds for specific separation. In particular the prominent forward projecting spines immediately behind the outer ends of the cervical sulcus are equally obvious in well preserved specimens from both horizons.

The Shenley specimens are generally slightly larger than those from the Cambridge Greensand and the Gault and some of them

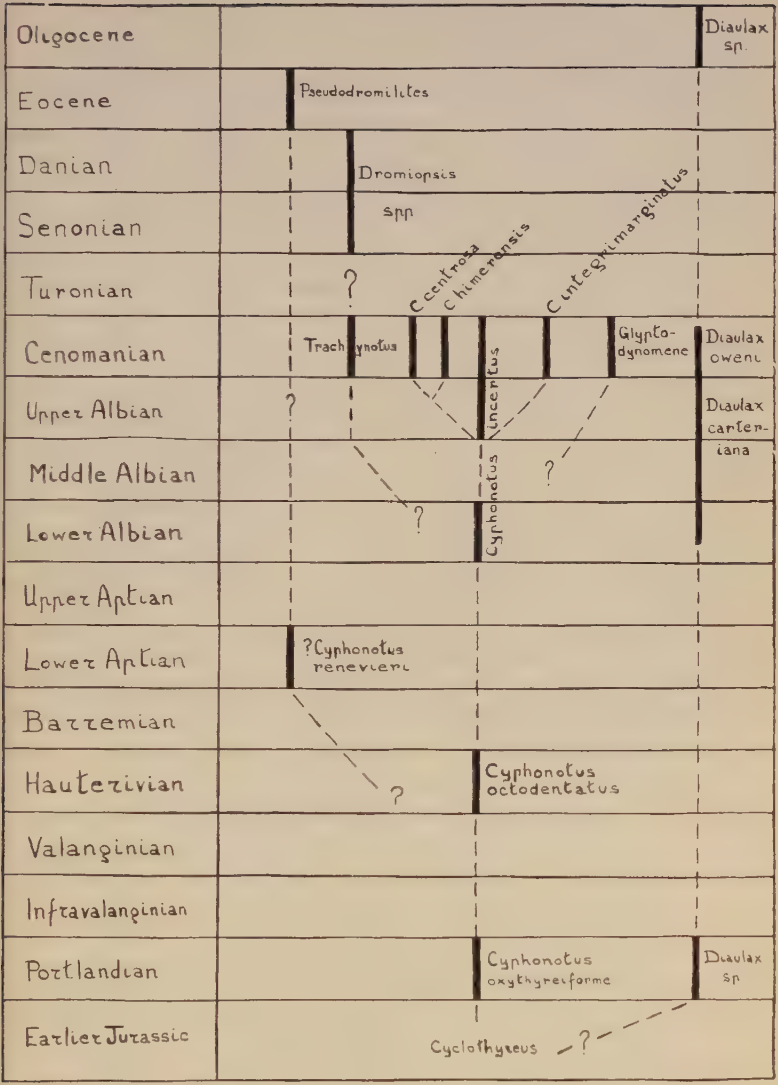


FIG. 13.—Evolution of certain early *Dynomenidae*

show well the fine even granulation on the upper surface of the carapace.

EVOLUTION OF CERTAIN EARLY DYNOMENIDAE

The table in Fig. 13 shows the range in time of the forms to which reference is made above and their suggested relations with each other and certain further genera of the family. *Cyphonotus oxythyreiforme* (Gemm.), *C. octodentatus* (A. Milne-Edwards), *C. incertus* Bell, *C. centrosa* Van Straelen and *C. himerensis* (Checchia-Rispoli) may safely be regarded as on or very close to a single line of descent. *C. integrimarginatus* sp. nov. is probably an offshoot of *C. incertus* Bell. *Trachynotus* Bell (sole species *T. sulcatus* Bell), though perhaps not so close to *Cyphonotus* as has been suggested, is probably derived from an early form of the genus, and in turn is close to the line of descent of *Dromiopsis*. De Tribolet's species *renevieri* is only doubtfully referred to *Cyphonotus* and if better known would probably have to made the type of a new genus. It is however almost certainly derived from a *Cyphonotus* or some similar form. It is of interest that the fragmentary holotype, in the very characters in which it differs from typical *Cyphonotus* (the distance apart of the orbits and the longitudinal sulci on the branchial regions) shows considerable resemblance to the Eocene *Pseudodromilites* Beurlen.

The strange genus *Glyptodynomene*, recently described by Van Straelen (1944) can perhaps best be attached at present to *Cyphonotus*, but the immediate ancestry of *Diaulax* which apparently ranges from the Portlandian (Glaessner, 1931) to the Miocene (Carter, 1898, p. 20) is not yet clear.

LIST OF WORKS CITED

Bell, T. 1863. A Monograph of the Fossil Malacostracous Crustacea of Great Britain London Clay, Gault, and Greensand. *Palaeont. Soc.*, London, Part II.

Beurlen. 1928. Die fossilen Dromiaceen und ihre Stammesgeschichte. *Pal. Zeit.*, 10, pp. 144–83.

Carter, J. 1898. A Contribution to the Palaeontology of the Decapod Crustacea of England. *Quart. Journ. Geol. Soc.*, 54, pp. 15–44.

Checchia-Rispoli, G. 1917. *Distefania*, nuove genere di Brachyuri del Cenomaniano della Sicilia, *Boll. Soc. Zool. Ital.*, ser. 3, V. 3, fasc. 12, pp. 174 *et seq.*

Gemmellaro, G. G. 1869. Studi paleontologici sulla fauna del calcare a *Terebratula janitor* del nord di Sicilia, Palermo.

Glaessner, M. 1931. Geologische Studien in den aüsseren Klippenzone. *Jahrb. Geol. Bundesanst*, Vienna, p. 1.

———. 1933a. Neues Krebsreste aus der Kreide. *Jahrb. Preuss. Geol. Landes* (1932), pp. 584–6.

———. 1933b. Die Krabben der Juraformation. *Centralblatt f. Min.*, 1933-B, pp. 178–91.

Remeš, M. 1895. Beitrage zur Kenntnis der Crustaceen der Stramberger Schichten. *Bull. Int. Acad. Sci. Bohème*, 2, pp. 200 *et seq.*

Van Straelen, V. 1936. Crustaces décapodes nouveaux ou peu connus de l'époque crétacique. *Bull. Mus. Roy. Hist. Nat. Belge*, 12, No. 45.

————. 1940. Crustacés Décapodes nouveaux du Crétacique de la Navarre, *ibid.*, 16, No. 4.

————. 1944. Anomoure et Brachyures du Cénomanian de la Navarre, *ibid.*, 20, No. 25.

de Tribolet, M. F. 1876. Description de quelques espèces de Crustacés Décapodes des étages Valanginien, Néocomien et Urgonien de la Haute Marne, le Jura et les Alpes. *Bull. Soc. Sci. Nat. Neuchâtel*, 10, pp. 299–300.

EXPLANATION OF PLATE 1

(All figures are natural size unless otherwise stated)

1. *Plagiophthalmus oviformis* Bell (a) top and (b) front views of specimen from the Cenomanian of Whitecliff, Seaton, Devon, showing the projection over the orbit when the shell is preserved. Authors' Collection No. 2179.
2. *Plagiophthalmus nitonensis* sp. nov. Top view of holotype from Lower Albian Carstone of Reeth Bay, Isle of Wight. Authors' Collection No. 10152.
3. *Goniodromites scarabaeus* sp. nov. Top view (× 2) of a paratype from same horizon and locality. Authors' Collection No. 15839. The front edge is missing in the centre.
4. *Goniodromites scarabaeus* sp. nov. Top view of holotype from Lower Albian Shenley Limestone of Munday's Hill Pit, Leighton Buzzard. GSM No. 88773.
5. *Goniodromites scarabaeus* sp. nov. (a) side and (b) front (× 2) views of a paratype internal cast from same horizon and locality. Authors' Collection No. 15837.
6. *Goniodromites scarabaeus* sp. nov. Top view of a paratype internal cast from same horizon and locality. Authors' Collection No. 10909.
7. *Cyphonotus incertus* Bell (a) top and (b) front views of an internal cast from the same horizon and locality. Authors' Collection No. 15833.
8. *Cyphonotus integrimarginatus* sp. nov. Top view of holotype from the Cenomanian of Wilmington, Devon. Authors' Collection No. 3540.
9. *Diaulax carteriana* Bell (a) top and (b) front views of an internal cast from the Lower Albian Shenley Limestone of Munday's Hill Pit, Leighton Buzzard. Authors' Collection No. 15834.

RECENT INVESTIGATIONS ON THE DEEP-SEA FLOOR

By J. D. H. WISEMAN, M.A., Ph.D., F.G.S., and C. D. OVEY, B.Sc., F.G.S., F.R.Met.S.[1]
Departments of Mineralogy and Zoology, British Museum (Natural History)

[*Received 27th October, 1949*]

CONTENTS

PAGE
1. INTRODUCTION 29
2. HISTORICAL SURVEY 30
3. ECHO SOUNDING AND RECENT BATHYMETRICAL CHARTS 31
4. MORPHOLOGY OF THE DEEP-SEA FLOOR 32
   (a) Elevations 32
   (b) Depressions 34
5. ORIGIN AND DATING OF DEEP-SEA MORPHOLOGY 35
   (a) Elevations 35
   (b) Depressions 40
6. INFLUENCE OF MORPHOLOGY ON SEDIMENTATION 44
7. DEEP-SEA CORING AND ITS IMPORTANCE IN RELATION TO PAST OCEANIC HISTORY 49
8. RADIOACTIVITY OF MARINE SEDIMENTS AND OF OCEAN WATER AND ITS USE IN MARINE CHRONOLOGY 54
9. THE SIGNIFICANCE OF PLANKTONIC FORAMINIFERA AS TEMPERATURE-INDICATORS IN CORES 57
   (a) Historical Survey 57
   (b) Test of the Validity of Planktonic Foraminifera as Temperature-Indicators 58
   (c) Further Physical and Ecological Considerations 63
10. NOTES ON THE FORAMINIFERA USED AS TEMPERATURE-INDICATORS 64
11. IMPLICATIONS OF CLIMATIC CHANGES FROM THE STUDY OF THE DEEP-SEA FLOOR 69
12. CONCLUSIONS AND ACKNOWLEDGMENTS 73
13. REFERENCES 75

SUMMARY—It is becoming evident that in order to interpret correctly the earth's history it is necessary to investigate the deep-sea floor, which covers approximately two-thirds of the earth's surface. Owing to the great increase of bathymetrical soundings with the development of the echo-sounder and the publication of bathymetrical charts, it has been possible to develop a rational classification of deep-sea morphological features. The origin of these features is discussed, and it is concluded that in general the ridges are compressional. The various methods by which it is possible to determine the age of formation of the deep-sea features are described, and specific examples are given where it has been possible to assign an age. The age of formation of the deep-sea basins is more difficult, but when more is known about the thickness of their sediments it may be possible to suggest an age. A study of the morphology of the deep-sea floor is important for genetical investigations on the sediments, and the various ways in which the features affect sediments are described. As satisfactory methods have now been developed for obtaining long cores from the deep-sea floor it is possible to investigate past oceanic history as far back as the Pliocene. The various methods by which past oceanic history may be revealed are described, and in view of the great difficulties of determining the cause of any chemical

---

[1] One of the authors (J.D.H.W.) is primarily responsible for sections 2-8, the other (C.D.O.) for sections 9-11.

changes with time, it may be necessary to express chemical composition on a constant titanium basis. The use of radium determinations for marine chronology is discussed, and the limitations of this method are described.

The use of planktonic foraminifera in the interpretation of climatic changes from washed core samples is discussed. The validity of these organisms is tested by an investigation of the faunal contents of nine bottom samples. These samples were selected, with the exception of one from the floor of the Ross Sea, from widely spaced localities, extending north–south through the Atlantic Ocean. From the examination it is clearly demonstrated that bottom assemblages of planktonic foraminifera reflect temperature changes in the surface waters of today and that these assemblages may, therefore, be used as a means of interpretation of past climatic changes revealed by core examination. Brief notes are given concerning the individual planktonic species used as temperature-indicators. A short survey of the implications of climatic changes from a study of the deep-sea floor is given, mentioning a few of the theories advanced to account for them in the Pleistocene and the dangers of arriving too hurriedly at conclusions from the analysis of only a few cores.

1. INTRODUCTION

ALTHOUGH the deep-sea floor is of considerable significance to geologists, as it not only represents approximately two-thirds of the earth's surface, but is also the environment in which so much marine sediment is deposited, relatively little attention has been given by them to its exploration. This neglect is doubtless due to the fact that there is endless geological exploration on the land surface where the rocks are generally readily accessible and where there are frequently good topographic maps. Deep-sea floor research on the other hand is essentially team work which is fraught with technical difficulties and financial obstruction. The best bathymetrical charts of the deep-sea are poor compared with normal topographic maps ; the sediments and rocks cannot generally be seen *in situ*, though there are interesting developments in the United States in connection with submarine photography (Shepard, F. P. and Emery, K. O., 1946)*.

It is only recently that suitable techniques have been developed for penetrating more than a metre into marine sediments (Kullenberg, B., 1947 ; Pettersson, H. and Kullenberg, B., 1941 ; Emery, K. O. and Dietz, R. S., 1941) thus revealing for the first time the sub-oceanic Pleistocene or even earlier succession ; and further, it is in general impossible to set specific limits to problems and to isolate them from other scientific subjects. In view of these circumstances it is not surprising that geologists have concentrated on the earth's visible surface where much information can be readily obtained by an individual or by a small team of workers. It is, however, becoming evident that excessive concentration on the visible portions of the earth's surface without regard to the invisible will retard the proper development of geology as an earth science, as well as perpetuating as dogma some theories which have little basis in fact. The purpose of this paper is therefore to attempt to assemble in an orderly way some of the important facts, and to point out the conclusions which may legitimately be drawn. It is the authors' hope that this will not only stimulate geological thought, but will also show some of the possibilities of the subject as a result of newly developed techniques. The paper should also be of interest to oceanographers and, as it will point out some of the more profitable lines for future work, it is hoped that it will be of some use to those who direct and plan oceanographical expeditions.

---

* For list of References see p. 75.

2. HISTORICAL SURVEY

Probably the first attempt at oceanographical investigation was the unsuccessful sounding by Magellan in 1521 to determine the depth of the Pacific Ocean during the first circumnavigation of the globe. As the length of sounding line carried by early explorers was only 100–200 fm. it is not surprising that Magellan did not reach the bottom, but he nevertheless concluded that he had reached the deepest part of the Pacific (Amoretti, C., 1801, p. 53). Robert Hooke (1667) devised an apparatus for sounding without a line. The principle of the apparatus was to determine depth from the time it took a weighted sphere to reach the bottom, where the weight was detached, and come to the surface again. The sphere was wooden and, to use Hooke's own words, " well secured by pitch or varnish or otherwise from imbibing water." Hooke carried out experiments in the Thames and off Sheerness, but attempts to use the apparatus in the Indian Ocean failed.

In 1773, during Lord Mulgrave's expedition to the Arctic, Capt. Phipps (1774) made a sounding of 1253 m. (685 fm.) from which he brought up a sample of blue mud from the Norwegian Sea. This is one of the earliest records on a chart of the nature of the sea-floor outside the limits of the continental shelf. Sir John Ross (1819, p. cxxiv) in his voyage to Baffin Bay took soundings up to 1920 m. (1050 fm.), and by means of an apparatus which he called a " deep-sea clamm," obtained bottom samples up to 6 lbs. in weight. Important soundings were obtained by the British Antarctic Expedition from 1839–43, and Sir James Clark Ross (1847, p. 26) obtained in January 1840 the first oceanic sounding in depths exceeding 3658 m. (2000 fm.). It is a remarkable fact that this early sounding is in agreement with the most recent bathymetrical chart of the South Atlantic (A'I, issued in 1936 by the International Hydrographic Bureau, Monaco).

From information obtained by the use of a new sounding apparatus with a detachable cannon-ball developed by Midshipman Brooke of the U.S.N., Maury (1855) published the first bathymetrical chart of the North Atlantic. The first trophies obtained by Brooke's apparatus were the bottom samples collected by the

U.S.S. *Dolphin* in the North Atlantic from a depth of over two miles. Part of these samples were sent to Prof. Bailey of West Point who made the first record of foraminifera from deep-sea deposits.

As a result of representations from the Royal Society to the British Government, the *Challenger* Expedition was despatched in December 1872 and returned in May 1876. Soundings were made during the expedition by means of hemp rope, and the time when each 100 fm. of it passed over the ship was noted. When the *Challenger* was being commissioned for her cruise Lord Kelvin was engaged in solving the problem of taking soundings with wire instead of hemp line. A sounding apparatus constructed by him was placed on board the *Challenger*, but the drum collapsed when first used. Lord Kelvin, however, was not dismayed and he improved his sounding apparatus which was used by the U.S.F.C. *Tuscorara* and U.S.S. *Blake*.

3. ECHO SOUNDING AND RECENT BATHYMETRICAL CHARTS

Owing to the time taken with wire apparatus the number of deep oceanic soundings increased slowly, but with the introduction of echo sounding the pace was completely changed. In echo sounding depth is determined by timing the interval it takes sonic or supersonic sound to travel from the surface of the ocean to the bottom and back again. The velocity of sound in sea-water, about 1463 m. per sec., being known, depth can be calculated with considerable accuracy (Boucart, J., 1949, pp. 17–37 ; Sverdrup, H. U. and others, 1942, pp. 74–80). The advantage of the echo sounder over the line method is first the great saving of time, as the ship does not need to be stopped, and secondly a continuous trace of the sea floor can be obtained. When comparison is made between a profile of the sea floor constructed from wire soundings and the same profile constructed from echo soundings, great irregularities are revealed ; the deep-sea floor is clearly much more irregular than was imagined by the early investigators who considered its slopes were smooth and gentle. In this connection it is interesting to compare bathymetrical charts published early in the present century with the most recent. It is clear that with the advance of knowledge there automatically follows increased morphological complexity.

Our knowledge of the morphology of the deep-sea floor is very limited in certain areas owing to the scarcity of soundings, e.g., in the South Pacific, South Indian Ocean and North Polar Sea. In the Atlantic Ocean recent coloured bathymetrical charts have been published by the International Hydrographic Bureau (BI, 1937 ; AI, 1935 ; A'I, 1936) a general coloured chart was issued in one of the *Meteor* reports (Stocks, T. and Wüst, G., 1935) and four of the more detailed uncoloured charts on a scale of 1:5,000,000 have been issued (Stocks, T., 1937, 1939 and 1941). Considerable attention has been given in the United States to the morphology of the North Pacific and the U.S. Hydrographic Office has issued some useful charts (Korea to New Guinea, No. 5485, 1946 ; North Pacific Ocean, No. 5486, 1939). Off the Californian coast Shepard and Emery (1941) studied in detail the bottom morphology of the continental borderland and the Geological Society of America issued four special charts. In the Western Pacific two recent charts have been issued by the International Hydrographic Bureau (AIII 1940 ; A'III 1942). The *Snellius* Expedition investigated the morphology of the East Indies (van Riel, P. M., 1934) and the geological interpretation of the bathymetrical results has been given by Kuenen (1935). An unnumbered bathymetrical chart of the South Pacific Ocean with contours at intervals of 914 m. (500 fm.) was issued by the U.S. Hydrographic Office in 1938. Bathymetrical charts of the Southern or Antarctic Ocean have been issued by the U.S. Hydrographic Office (No. 2562, 1947), the Department of Interior, Canberra, 1939, and by the *Discovery* Expedition (Herdman, H. F. P., 1948). This publication dealing with the soundings taken by the *Discovery* from 1932–9 is important, because it contains a chart of the South Sandwich Trench. The John Murray Expedition to the Arabian Sea (1933–4) investigated the morphology of the Arabian Sea, and the results are incorporated in bathymetric charts (Farquharson, W. I., 1936), the geological interpretation being given by Wiseman and Sewell (1937). Stocks (1941a, 1942) has published interesting bathymetrical charts of the Gulf of Aden and Arabian Sea. The same author (1941b) has also discussed the size of the North Polar Basin. This basin has been the subject of a recent investigation by Emery (1949).

4. MORPHOLOGY OF THE DEEP-SEA FLOOR

(a) Elevations

It is clear from the foregoing summary that there is rapidly accumulating a wealth of bathymetrical information which is of considerable importance to the study of world tectonics, and in consequence it may be of some interest to describe some of the morphological features found on the deep-sea floor. These features are at present under consideration by an International Committee set up by the International Union of Geodesy and Geophysics[1] as well as by a Sub-Committee of the Royal Society, and it is hoped that a special report will be published in 1951. For convenience the features found on the deep-sea floor may be divided into (a) elevations and (b) depressions. A rise is an extensive, long and broad elevation which rises gently from the deep-sea floor, whilst a ridge is a long and narrow elevation having steeper sides and rougher topography than those of a rise. The best known ridge is undoubtedly the Mid-Atlantic Ridge, which extends with one break—the Romanche Gap—from Iceland to 55° S. where it runs eastward towards Bouvet Island. Various ridges or rises run transversely from the Mid-Atlantic Ridge towards the coasts, thus dividing the Atlantic into a series of basins (Stocks, T. and Wüst, G., 1935, p. 22), but it is possible that some of the supposed transverse ridges do not merit individual names (van Riel, P. M., 1940, p. 43). The Mid-Atlantic Ridge has in the South Atlantic an average depth of 2000–3000 m. (1094–1640 fm.), whilst the deepest part of the basins on either side is between 5000–6000 m. (2734–3281 fm.). In the North Atlantic up to 28° N. the Ridge is on the average slightly deeper, 3000–3500 m. (1640–1914 fm.), with basins on either side with a maximum depth greater than 6000 m. (3281 fm.). North of that latitude the depth of the ridge gradually decreases. It is of some interest to point out that the island of Flores in the Azores lies on the general trend of the Mid-Atlantic Ridge whilst the other islands lie on ridges at right angles to that direction (Wüst, G., 1939).

---

[1] Nature, 163, 1949, p. 316.

A submarine ridge separating partially closed basins or troughs from one another or from the adjacent oceans is in oceanographical parlance called a sill. The sill depth, or the greatest depth over the sill, is important to the geologist because it controls to a large extent the type of sediment accumulating in a basin.

Isolated but extensive rises in the deep-sea floor with a comparatively broad and flat top are known as table-mounts. A good example is the *Discovery* Table-mount, 42° S. on the Greenwich meridian, which rises from an average depth of 4572 m. (2500 fm.) to less than 500 m. (273 fm.). The rise of the bottom on the northern side is fairly steep, the average slope being about 10°, whilst on the southern slopes the average slope rarely exceeds 4°. It would seem that the surface of the table-mount is to a large extent devoid of sediments because the trawl brought up rocks, one of which is a foot in length. These rocks have been recently examined and found to be basalts. It is not definitely known whether they are representative of the foundations of the *Discovery* Table-mount, for although icebergs do not normally go so far north, it would nevertheless be possible to suggest that they are erratics transported during the glacial period. Against this theory is, however, the fact that the rocks are all of one type and do not show any glacial striae.

Isolated mountain-like structures which rise abruptly more than 914 m. (500 fm.) from the deep-sea floor are known as sea-mounts. The shape of these structures is frequently suggestive of a volcanic origin, as the slope is sometimes 20° or more and is concave upwards. Sea-mounts, some of which have flat tops, are abundant in the Gulf of Alaska (Murray, H. W., 1941). They are generally discovered in large numbers wherever detailed surveys are made. The *Altair* Sea-mount (43°33′ N., 33°58′ W.) is situated north-west of the Azores, and was surveyed in 1938 (Wüst, G., 1940, p. 16) during the course of the International Gulf Stream Expedition. This sea-mount rises from a depth of 3500 m. (1913 fm.) to 973 m. (532 fm.), has slopes of 22½° and in one place 52° over a distance of nearly half a sea mile. It is considered by Defant and Helland-Hansen (1939, p. 43) to be a volcanic cone. A volcanic sea-mount which just comes to the surface is Bogoslof Island in the Bering Sea ; a detailed survey (Smith, P. A., 1937) has shown that it rises abruptly from a depth of 1400 m. (766 fm.). Tristan da Cunha, situated to the east of the summit of the Mid-Atlantic Ridge, is essentially a sea-mount and rises within 12 miles from a depth of approximately 3658 m. (2000 fm.). The maximum slope is 25° (Herdman, H. F. P., 1948, p. 83). Isolated submarine hills which are smaller and less prominent than table- or sea-mounts are called knolls.

Guyots are sea-mounts with flattened tops and occur generally between depths of 914 m.–1646 m. (500–900 fm.). Sometimes, as in the case of Eniwetok Guyot, the outer rim of the top is bevelled by a gently sloping shelf 1 to 2 miles in width which is about 130 m. (71 fm.) deeper than the inner margin. The gentle slope changes abruptly to 22° at the outer margin, and the profile thence to the ocean floor is concave upwards.

(b) Depressions

The German Oceanographical School, headed by Wüst (1940a), advocated a three-fold division for depressions. To the extensive depressions on the sides of the median ridges the term “ Mulde ” or trough was given, e.g., the West Atlantic Trough. The troughs are divided by transverse ridges (Swellen) into basins (Becken), e.g., the North American Basin. The long and relatively narrow depressions occurring in some of the deep-sea basins were called trenches (Graben). The words trough, basin and trench are, therefore, used by Wüst in the order of decreasing magnitude. Although there is some justification for this ideal synthesis where there is a well-defined median ridge, e.g., the Atlantic Ocean, such a scheme cannot be applied to the Pacific or Southern Oceans. Furthermore, a basin can be large or small and, as will be shown later, the real difference between trough and trench is not size but origin. In view of these considerations, the German terminology is unsatisfactory, and a less exact terminology is proposed. A basin is in consequence a depression in the deep-sea floor more or less circular in form but not necessarily large and pronounced. In the East

Indies, Kuenen (1935, p. 37) has attempted a morphological classification depending on their shape and cross section. A trench is a long but narrow depression in the deep-sea floor normally with steep sides, whilst a trough is a long depression in the deep-sea floor with more gently sloping sides. Trenches are invariably associated with island arcs or along tectonically active borders of continents, and normally have depths greater than 7000 m. (3828 fm.). Although the well-established term " deep " is unfortunate as there is no morphological importance attached to this feature, it is nevertheless well-rooted in oceanographical tradition and should be restricted to greater depths than 5486 m. (3000 fm.). A gap, e.g., the Romanche Gap, is a steep furrow which cuts across a ridge or rise.

5. ORIGIN AND DATING OF DEEP-SEA MORPHOLOGY

(a) Elevations

As it will doubtless be many years before a satisfactory theory is developed concerning the fundamental origin of deep-sea features, it is perhaps advisable at the present stage to recall some of the important facts which are reasonably established and the deductions which may be drawn. Such an approach will suggest lines upon which future work should be done, in order to show whether the general deductions are fundamentally correct or whether they require modification. It would then be possible to determine whether these deductions are in agreement with geophysical speculation concerning the fundamental origin of these features, and therefore give a test to the validity of such theories (Holmes, A., 1933 ; Meinesz, F. A. V., 1934 and 1948 ; Umbgrove, J. H. F., 1945 and 1947).

A glance at any modern bathymetrical chart shows that it is the exception for the deep-sea floor to be flat, in spite of the fact that deposition is taking place, which should smooth the irregularities. It must, however, be realised, as has been pointed out by Shepard (1948, p. 310), that as submarine volcanoes and mountain ranges are not subject to erosion until they reach the zone of wave action, all features of this nature formed during the geological existence of the ocean will retain to a great extent their original morphology. It will be shown later that the great oceanic ridges are in all probability diastrophic effects accompanied in places by vulcanism, and in consequence the morphology of the deep-sea floor is essentially a balance between the smoothing effects of deposition and the roughening effects of diastrophic and volcanic action.

In studying these ridges it is of great importance to note that nearly always where they are sufficiently elevated to appear above the surface of the ocean, the islands thus formed are of volcanic origin. The Seychelles which lie on the Mascarene Ridge are, however, partially composed of granite, whilst St. Paul's Rocks on the Mid-Atlantic Ridge are dynamically metamorphosed ultrabasic rocks (peridotites and dunites) (Tilley, C. E., 1947 ; Washington, H. S., 1930). The Azores which lie on the Mid-Atlantic Ridge are largely volcanic, but there is a small deposit of limestone containing marine shells of Miocene age on Santa Maria. It is interesting to note that on Ascension Island xenoliths of an alkaline hornblende-granite as well as olivine-gabbro occur in addition to the usual basalt. Daly (1925, p. 76) considers that these may represent fragments of the older terrain upon which Ascension Island rests. St. Helena, Tristan da Cunha, Inaccessible Island, Nightingale Island and Gough Island, which lie to the east of the summit of the Mid-Atlantic Ridge, are volcanic sea-mounts.

There is little evidence regarding the submarine composition of these ridges, but in the North Indian Ocean rock fragments have been obtained from the middle part of the Arabian Ridge (Wiseman, J. D. H., 1937), whilst the *Meteor* Expedition (Correns, C. W., 1930, p. 76) obtained basaltic fragments from the Mid-Atlantic Ridge. More recently basalts, serpentines and mylonitised anorthositic gabbros have been dredged from the Mid-Atlantic Ridge (Shand, S. J., 1949). On the basis of the above facts it may be concluded that although the great oceanic ridges exhibit volcanic activity it does not necessarily follow that their morphology is due to this cause alone, because diastrophic activity is generally accompanied by vulcanism.

A study of the morphology of these ridges suggests that they have a diastrophic origin, as they show many features indicative of compression. For example, cross-section echo profiles frequently show rises or falls of 500–1000 m. (273–546 fm.) within a distance of ten kilometres. The feature is well shown in the echo profiles across the series of soundings of the Mid-Atlantic Ridge made by the *Meteor* Expedition (Maurer, H. and Stocks, T., 1933 ; Pettersson, H., 1948, pp. 44–60). Wherever the ridges have been surveyed in any detail there is a regular alternation of slightly curved elevations and depressions of considerable length, and frequently the elevations gradually decrease in height along the length and are replaced sidewards by others of increasing intensity, thus establishing an *en echelon* structure. Such structure is characteristic of compression, e.g., the Swiss Jura, and is absent in block faulted or tensional structure. This relationship can be established on the bathymetrical charts of the Mid-Atlantic Ridge in the neighbourhood of the Azores (Wüst, G., 1940). Similar features have been found as a result of the detailed survey carried out by the *Snellius* Expedition in the East Indies, and Kuenen (1935, p. 35) considers these are produced by compression. Alternations of depth were found on the Arabian Ridge in the North Indian Ocean by the John Murray Expedition, and Farquharson (1936, p. 53), the surveyor of the expedition considers, "that the ridge as a whole presents the appearance of a series of sharp folds gradually rising from the bed of the ocean and culminating in two or more folds of approximately equal height."

Some of the ridges have elongated deep areas running in the general direction of the ridge surrounded by shallower soundings. An example on the Mid-Atlantic Ridge is the Hirondelle Furrow, which has a greater depth than 3000 m. (1640 fm.) and the saddle depth, as determined from potential temperature considerations, is about 1800 m. (984 fm.). Similar furrows occur in the Arabian Ridge.

It would, in view of these facts, seem a justifiable conclusion to regard the great ocean ridges, exhibiting in places volcanic action, as essentially compressional features.

The dynamic metamorphism of the St. Paul's Rocks gives considerable support to the theory of compression, as was originally pointed out by Washington (1930a, p. 20). Recent work on the St. Paul's Rocks (Tilley, C. E., 1947) supports this conclusion. It is pointed out by Tilley that in the case of the St. Paul's Rocks the lattice orientation of the olivine has (010) parallel to the foliation, i.e., α is perpendicular to the foliation, and that this orientation is in harmony with stressed peridotites from other regions where the grain-size has permitted a petrofabric analysis to be made. It should in consequence be possible, provided rock specimens of known orientation are collected from the St. Paul's Rocks, to determine the direction of stress. The mylonitised anorthositic gabbro dredged by the *Atlantis* 1947 Expedition from a depth of 1463 m. (800 fm.) on the Mid-Atlantic Ridge at 30°06′ N., 42°08′ W. gives additional evidence about strong shearing stresses (Shand, S. J., 1949, p. 91).

Deep-sea ridges which exhibit broad corrugations are therefore classed as geanticlines and it is of interest to point out that Hess (1948, p. 425) came to a similar conclusion for the ridges in the western north Pacific. It is impossible to say whether the ridges have minor corrugations, as such features at a depth of 2000–4000 m. (1094–2187 fm.) would not show on the echo profile because the supersonic sounder is not perfectly directional but sends out its energy in the form of a cone with an angle of about 15°.

The theory that deep-sea ridges are compressional features is by no means new, as Emil Haug (1907, p. 164) suggested that the Mid-Atlantic Ridge was an anticline and the Atlantic Ocean a great geosyncline. A tensional hypothesis was advocated by Taylor (1910, p. 218) who said that it was a horst that "has remained unmoved while the two continents on opposite sides have crept away in nearly parallel and opposite directions." The view is practically the same as that of Wegener (1924, p. 61) who regards the islands of the Mid-Atlantic Ridge as fragments of the margin of the rift, whilst Daly (1926, p. 280) considers it as a long strip which was left behind when the original continent was torn into fragments. The morphological evidence does not, however, support the tensional theory, nor can the ridges be regarded as sunken remnants of old mountain chains, because there is no evidence, so far as the authors are aware, for the existence of a sunken wave-cut platform on the slopes of the ridges. Narrow terraces at a depth of 3658 m. (2000 fm.) have, however, been found on the flanks of the Mid-Atlantic Ridge (Ewing, M., 1948, p. 286) and it is of some interest to recall that below these terraces the thickness of sediments is of the order of thousands of feet.

It would seem a justifiable conclusion from the morphology of sea-mounts that they are generally volcanic peaks. Definite evidence for a volcanic origin is given by volcanic oceanic islands. It is of some interest to point out that sea-mounts occur not only on the tectonic lines of diastrophism indicated by the geanticlines, but also in oceanic basins. It is difficult to give any definite origin for the larger and isolated mountain-like structures known as table-mounts ; the authors are unaware of any detailed work that has been done on them. Possibly some may be composite sea-mounts, others may be isolated dome structures, modified by volcanic action, and a final possibility is that they are fault blocks.

Guyots according to Hess (1946, p. 789) are Pre-Cambrian islands which have undergone marine planation and have subsequently been submerged partially through the accumulation of sediments in the ocean since Pre-Cambrian times. The investigations on Bikini Atoll have given important evidence concerning the formation of guyots as the seismic profiles have shown (Dobrin, M. B. and others, 1949, p. 808) that the high velocity material comparable to basalt, granite and possibly compact limestone, reaches a maximum depth of 3961 m. (2166 fm.) on the east side of the atoll, and rises to 2132 m. (1166 fm.) at a point slightly to the west of the north–south centre line of the atoll. It is thus clear that the volcanic core of the atoll forms a peak located eccentrically with respect to the present atoll, and Hess (1948a, p. 297) has pointed out that this is doubtless due to the more rapid and vigorous growth on the windward side of the atoll. In consequence, the volcanic core would lie not under the centre of the atoll but would be displaced toward the lee side, which is the west side in the case of Bikini. A similar conclusion is implicit from the magnetic results of the Royal Society investigation of Funafuti (Creak, E. W., 1904, p. 36) where the greatest magnetism was found close to the western margin. Hess also points out that in view of the more rapid growth of coral on the windward side there will be eccentric loading, and as a consequence of isostatic adjustment there will be a tilting of the old volcanic floor.

It is difficult to determine when elevations originated, and it is in general only possible to give broad limits to their age. It has been possible in a few favourable cases to suggest the age of the isolated deep-sea features, namely table-mounts, sea-mounts and guyots. One example is Providence Island which is a small reef (9°20′ S., 51°15′ E.) NNE. of Cape Amber, Madagascar. This island is one of a series resting on a plateau, the base of which lies at approximately 3000–3500 m. (1640–1914 fm.). At a depth of 1361 m. (744 fm.) the Percy Sladen Expedition (Wiseman, J. D. H., 1936) recovered a rock which consisted of altered basaltic fragments cemented with calcite. The occurrence of an oribitoidal foraminifer in it proved that the volcanic foundation to Providence Island is in all probability of Eocene or Oligocene age. The occurrence of fossiliferous deposits on sea-mounts gives a useful age indication. In a core from the top of a sea-mount NE. of Bermuda (about 34° W., 62° N.) Ewing (1948, p. 279) records the occurrence of Eocene foraminifera in a white chalk below an 8 m.-thick surface layer.

Proof that the volcanic foundations to some of the atolls in the Pacific are of considerable age is given by the 2500-foot boring on Bikini in the Marshall Group. From a depth of 1790 feet to the bottom of the bore Miocene fossils were found, and as there may be 5000 feet or more of older calcareous sediment before reaching the volcanic floor of the atoll it is reasonable to regard the foundation as of pre-Miocene age.

Although the occurrence of " datable " rocks on oceanic islands situated on geanticlinal structures gives information about the date of emergence, it is only in favourable circumstances that it suggests the date of the localised compressional forces responsible for these structures. For example, at Santa Maria in the Azores there is a small deposit of limestone of Miocene age. Although this indicates that Santa Maria was last elevated since the Miocene it gives no information as to when the geanticline was formed, as the island may have been elevated above sea-level through later eustatic movements. Even if unfolded sedimentary rocks of known age occur it does not necessarily follow that the age of the compressional forces through which the geanticline originated preceded the deposition of these sediments, because it is possible that the parts of the geanticlines which emerge above the sea level are not folded into normal anticlines and synclines, as in the upper layer of the continental crust. If, however, unfolded sedimentary rocks of known age rest upon a regionally metamorphosed sedimentary series it is legitimate to conclude that the deformation producing the geanticline was responsible for the metamorphism and was consequently before the age of the " datable " sedimentary rocks. By this means it has been found possible to date tentatively the geanticlinal structures (Palau-Kyushu, West Caroline, Iwo Jima and the Mariana geanticlines) found in the western north Pacific. Hess (1948) considers that the deformation responsible for these structures preceded deposition of the Eocene Nummulitic Limestone, and was probably late Cretaceous, because there are no unmetamorphosed Mesozoic rocks on the islands situated on the geanticlines. It would be of great interest to collect orientated specimens of the metamorphic rocks from these islands, as it might be possible from the lattice orientation of the minerals to determine the direction of the force responsible for their formation. According to Hess the dating of peridotites is an important tool in dating these structures, because they are intruded during the first great deformation of the belt and later deformations are not accompanied by similar intrusions. Thus the occurrence of a peridotite belt of known age indicates not only the old tectogene axis, but also the date of the initiation of deformation of that zone. On this basis the Nansei Shoto geanticline is considered to be of mid-Mesozoic age.

(b) Depressions

As elevations emerge sometimes above sea-level it is to be expected that there would, in general, be less morphological and geological information about depressions. In view of recent deep-sea soundings it is, however, possible to give a rational morphological classification, but until more evidence is forthcoming about the deeper strata underlying the surface deposits only tentative conclusions can be made.

Depressions may be classified into two essentially different groups. First there is the ideal basin characterised by a flat horizontal bottom and gently sloping sides. The majority of deep-sea basins differ, however, from this ideal type, because their floors are irregular. Sea-mounts, guyots, table-mounts and fault blocks may rise to relatively shallow depths from the deep floor of the basin. Further, the rim of the basin is not at a constant depth, and the saddle depths between one basin and another may be 4500 m. (2461 fm.) or more. The second group are depressions of great depth, which are long, frequently curved, but relatively narrow in comparison with their length. It is here that the greatest depths of the oceans are found. These features are associated with island arcs or along tectonically active borders of continents, and in cross section are gently sloping synclines with a maximum depth of more than 7000 m. (3828 fm.). Such features taper towards their ends, and the depth varies along their length. On the concave side these depressions slope down from relatively shallow depths, whilst their boundary on the convex side is frequently characterised by the 6500 m. (3554 fm.) contour. To these features the term trench is applied, and typical examples are found in the East Indies (Kuenen, Ph.H., 1935, p. 41 ; van Riel, P. M., 1934, plate II). The Java Trench has a maximum depth of 7450 m. (4074 fm.), whilst the greatest depth 10497 m. (5740 fm.) so far recorded occurs in the

Mindanao Trench, off the Philippines. This well-established depth was obtained by the U.S.S. *Cape Johnson* on 14th July, 1945 at 10°27′ N., 126°36′ E. In a paper shortly to be published on "The greatest depth in the oceans" by H. H. Hess and N. W. Buell, Jnr., it is shown that the deepest sounding, 10791 m. (5900 fm.), obtained by the German cruiser *Emden* on 29th April, 1927, is spurious, and is due to an echo from the hard side slopes of the trench and not from the soft deposit immediately below the ship. The Timor-Ceram Trench is much shallower, and is not typical, because the depths on its convex side are less than 100 m. (55 fm.). In the West Indies the Puerto Rico Trench (maximum depth 9219 m.) (5041 fm.) is a good example (Vaughan, T. W., 1940, p. 71), whilst in the Southern Ocean the South Sandwich Trench (Herdman, H. F. P., 1948, p. 62) has a maximum depth of 8264 m. (4519 fm.) and extends for a distance of approximately 650 miles at a depth of 5000 m. (2734 fm.). In the North Pacific there are many trenches associated with the island arcs (Bryan, G. S., 1940, chart No. 5486 ; Hess, H. H., 1948, p. 421), e.g., the Aleutian Trench, 7679 m. (4199 fm.) ; Kuril Trench, 8513 m. (4655 fm.) ; Japan Trench, 9802 m. (5360 fm.) ; the Bonin Trench, 8650 m. (4730 fm.) ; Marianas Trench, 9569 m. (5269 fm.) ; West Caroline Trench, 7498 m. (4100 fm.) ; and the Nansei Shoto Trench, 7324 m. (4005 fm.). The morphology of the South Pacific Ocean is, as previously remarked, not well known. The Kermadoc-Tonga Trench, 9427 m. (5155 fm.), extends over 22° of latitude, and the New Britain-Bougainville Trench, 9140 m. (4998 fm.), including its probable continuation the New Hebrides Trench, 7567 m. (4138 fm.), are both associated with island groups. The South America Trench, 7635 m. (4175 fm.), extending from approximately 8°–34° S., runs parallel to the west coast of South America. The origin of this trench, isolated for roughly two thirds of its length from the deep Pacific floor by the Juan Fernandez Ridge, is obscure. The maximum depths of the trenches associated with island arcs, apart from the exceptional Timor-Ceram Trench, varies from 7000 to over 10,000 m. (3828–5468 fm.). As the maximum depth, apart from a few exceptional cases, of the deep-sea floor rarely exceeds 6500 m. (3554 fm.) it is concluded that the trenches represent features of special tectonic significance normally associated with these arcs.

In addition to the trenches there are a few long and relatively narrow depressions in the deep-sea floor which are not associated with island arcs, and as they have a different origin it is proposed that the term trough should be reserved for them. A typical example is the Bartlett Trough in the Caribbean Sea with a maximum depth of 7238 m. (3958 fm.). This is considered to be a block fault (Hess, H. H., 1938, p. 87) which was formed during the late Miocene deformation. It is of some interest to note that horizontal movement took place along the north side of the Bartlett Trough, the south side moving east. There are, however, a few isolated deep depressions which cannot, with any degree of certainty, be called troughs. It will doubtless be possible, when more is known about the morphology of these deep depressions, to suggest a correct structural classification. In the meantime it is convenient to retain for such features the term " deep," e.g., the Byrd Deep, 8581 m. (4692 fm.), situated in the South Pacific 61°06′ S., 179°00′ E., especially as there is no morphological significance attached to this term.

Concerning the origin of the deep-sea basins there is little information, because their formation is clearly associated with the origin of the oceans. If the theory of continental drift is omitted their origin must, in general, be explained through faulting, folding or warping.

Before any general theory can be developed more information is clearly necessary concerning the origin of the continental slope, and the depth of the underlying crystalline rocks. An interesting start has been made in the United States (Ewing, M. and others, 1937, p. 811 ; 1946, p. 918), where it has been shown by geophysical methods, that off Cape Henry and Jacksonville, crystalline rocks underlie coastal sediments. The surface of the old crystalline mass slopes eastward, and at the edge of the continental shelf it has reached a maximum thickness of 3599 m. (1968 fm.). This evidence suggests that the floor of the North American Basin has subsided, and it is of some interest to recall that Prof. Ph.H. Kuenen (Wiseman, J. D. H., 1949, p. 683) considers that there has been isostatic subsidence off Cape Hatteras due to the weight of the sediment. It has been found that on the continental shelf to the west of the English Channel the thickness of the sediment increases on receding from the land, and at the edge of the continental shelf the thickness of the sediment is 2438 m. (1333 fm.) (Bullard, E. C. and Gaskell, T. F., 1941, p. 494).

The margins of oceanic basins may, however, be faults, as shown by Shepard (1941, p. 46 and charts, I, II, III, IV). In the region to the west of the Californian coast there is for more than 10° of latitude an immense submarine escarpment generally of more than 2500 m. (1367 fm.). A somewhat similar faulted margin would seem probable for the Somali Basin and the Arabian Basin in the North Indian Ocean (Wiseman, J. D. H. and Sewell, R. B. S., 1937, p. 223). Recently the Eocene planktonic genus *Hantkenina* has been identified by one of the authors (C.D.O.) from the continental slope west of Finistère (unfortunately the exact locality cannot be traced but it approximates to 47½° N., 08¾° W.) at a depth of 2743 m. (1500 fm.) in a sample of anchor-mud collected by H.M. T.S. *Monarch* and separated by Mr. S. Waller. The specimens are of a different species from that found in the Eocene "Blue Marl" of Biarritz which was recorded by Halkyard (1919, p. 127) as *Nonionina kochi*

(Hantken). Specimens of the latter are preserved in the collections of the British Museum (Natural History). Upper Cretaceous foraminifera are also found in the same sample including ? *Reussella* [*Bulimina*] *limbata* (White)—a species described from the Upper Cretaceous (Mendez Formation) of Mexico, and recognised by Mr. T. F. Grimsdale who kindly examined the sample—*Stensiöina pommerana* Brotzen (Maestrichtian) and *Pseudotextularia fruticosa* (Egger) (Senonian). It is interesting to recall that in the sediments from the continental shelf of the east coast of the U.S.A. Stetson (1949) has recorded Upper Cretaceous, Eocene, Miocene and Pliocene sediments.

There is at present little information concerning the age of formation of deep-sea basins. It may, however, be possible when more is known about the character and thickness of the sedimentary cover to give them an approximate age, on the assumption that the rate of sedimentation throughout the sedimentary columns approximates to the average rate, as determined by radioactive and other methods, for the Pleistocene. Weibull (1947) was the pioneer in developing a suitable apparatus for the rapid determination of the thickness of the sedimentary cover on the deep-sea floor. His apparatus was used on the recent Swedish Deep-Sea Expedition, and according to a personal communication it is evident that great improvements have been made in technique, and that it is now possible to distinguish reflecting layers separated by only 20 m., (11 fm.). In the red clay area of the East Atlantic Basin (30°46′ N., 25°15′ W.) Weibull has established three reflecting surfaces at 1540 m. (842 fm.), 2220 m. (1214 fm.) and 3460 m. (1892 fm.). These thicknesses would have to be increased by at least 20 per cent on account of the higher velocity of sound in sediment than in sea-water. If it is assumed that the sedimentary column is composed, apart from the reflecting layers, of red clay with an average rate of sedimentation of 1 cm. in 1000 years then the total time required for its accumulation would be at least 400 million years, i.e., at least a portion of the East Atlantic Basin would be in existence in Silurian times. The thickness of the sedimentary cover in the Pacific and Indian Oceans is much thinner than that found in the Atlantic, and rarely exceed 400 m. (219 fm.). It would seem that there are in these two oceans lava beds intercalated with the marine sediments (Petterson, H., 1949a, p. 469). Recent seismic refraction measurements (Ewing, M. and others, 1949) in the North American Basin at 34° N., 66°30′ W. indicate a sedimentary cover of 1372 m. (750 fm.) over a basaltic substratum. It is evident that at this locality there is no granitic or intermediate layer.

The gravity surveys carried out both in the English Channel and in the region to the west of the continental shelf suggest the possibility of sedimentary pockets in the deep-sea floor (Browne, B. C. and Cooper, R. I. B., 1950). It has been found that the average isostatic anomaly at sea level for stations outside the limits of the continental shelf is 11 mgl. with a scatter of ± 19 mgl., whereas on the continental shelf the average is + 7 mgl., with a scatter of ± 10 mgl. At a level of 1500 m. above the continental shelf the scatter would be reduced to ± 7 mgl., and in consequence the scatter over the deep-sea is many times greater than it is over the continental shelf. It is possible to explain the increased scatter if the deep-sea floor is composed of blocks of granite set in a matrix of basalt, or alternatively if there are huge pockets of sediment. The latter hypothesis is supported by seismic refraction work carried out in the summer of 1949 by Mr. M. N. Hill of the Department of Geodesy and Geophysics, Cambridge University. Preliminary results indicate that there is a sedimentary layer of at least 2615 m. (1430 fm.) covering a high velocity substratum, in the neighbourhood of 53°50′ N., 18°40′ W.

There are, however, in some of the basins within the island arcs definite geological indications as to time and nature of origin. For example, as pointed out by Umbgrove (1949, p. 20), if a thick series of relatively recent elastic non-volcanic sediments are found on an island which is surrounded by a deep-sea basin one is forced to conclude that there was a land area on the site of one of these basins when the sediments were deposited, and in consequence the origin of the basins is relatively recent. Confirmatory evidence of recent origin is given if Upper Tertiary anticlines are intersected at a sharp angle by the coast-line of an island. Such is the case on the South Celebes, in the neighbourhood of Buton, where Upper Tertiary anticlines are intersected at right angles by the coast-line of the Bone Basin of greater depth than 2000 m. (1094 fm.). It has, therefore, been concluded by both Umbgrove and Kuenen that the basins of the East Indies are of recent formation.

Much has been written about the origin of deep-sea trenches associated with island arcs and there is a general concensus of opinion (Kuenen, Ph.H., 1935 ; Umbgrove, J. H. F., 1949 ; Hess, H. H., 1938) that they are formed by compression. Deep-sea trenches are invariably associated with gravity anomalies (Meinesz, F. A. V., 1934, 1948 ; Hess, H. H., 1938 ; Heiskanen, W., 1945), seismic activity (Gutenberg, B. and Richter, C. F., 1941), and vulcanicity. The date of their formation is closely related to the age of the associated structures.

6. INFLUENCE OF MORPHOLOGY ON SEDIMENTATION

The morphology of the deep-sea floor has a profound influence on the character of sediments, and in consequence genetical investigations on deep-sea sediments necessitate a study of morphology. Deep-sea features may affect sediments in three essentially different ways ; first through slumping, secondly through their influence on texture, and thirdly through their chemical and environmental influence.

It is possible that slumping may take place on gentle slopes, though Kuenen (1943, p. 34) is disposed to consider that it is a rare phenomenon as " our data prove beyond doubt that the most mobile marine sediments known can accumulate in thickness of upwards of 1 m. on angles of 15° in strongly seismic regions in all depths." Slumping in lakes and inland seas where the slopes are less than 3° (Archanguelsky, A. D., 1930; Heim, A., 1908); the slump which broke the submarine cable off the Newfoundland Banks in November 1929 (Stetson, H. C., 1938), and the increasingly frequent discovery of slumping in sedimentary geological strata (Jones, O. T., 1937 ; Kuenen, Ph.H., 1949), cause the authors to urge strongly that it is desirable before taking a core to determine whether the sea-floor is reasonably horizontal both in the direction of traverse and at right angles to it. Some of the features by which slumping may be recognised have been described by Bramlette and Bradley (1942, p. 15). It is clear that if material is thrown into suspension by a slump, it will be deposited more or less according to its grain size, and hence a sharp transition from clay to a sand gradually decreasing in particle size in an upward direction is indicative of slumping.

Trask (1932, pp. 83–95) was one of the first to point out that the texture of the sediments is more closely related to morphology than to actual depth or distance from shore. Non-depositional surfaces, as indicated by a rock bottom, are frequently found on the tops of elevations such as table- or sea-mounts. Good examples occur off the west coast of California where the flat top of the San Juan Sea-mount (Shepard, F. P., 1941, p. 1887), which rises approximately 3000 m. (1640 fm.), from the sea floor, is completely devoid of mud or sand. Similarly many of the table-mounts, e.g., the *Discovery* Table-mount (Herdman, H. F. P., 1948, p. 92) are swept clear of recent sediments whilst if any sediment is found on ridges it is normally of sand size, e.g., on the Faraday Hills, Mid-Atlantic Ridge (Bramlette, M. N. and Bradley, W. H., 1940, p. 6). The sides of table- and sea-mounts are, at least in places, devoid of sediments, because rock fragments have been obtained from their slopes (Shepard, F. P. and Emery, K. O., 1941, p. 27 ; Wiseman J. D. H., 1936). Non-depositional areas may occur on the deep-sea floor (Pettersson, H., 1948, p. 235) and this frequently takes place where the deep-sea floor rises slightly above the general level of the basin.

The discovery of all the agents necessary for the transportation of material along the deep-sea floor is unlikely to be made until more physical observations have been taken on oceanic bottom water. For the transportation, apart from that caused through slumping, of sediments resting on a slope or towards the top of a ridge, all that is necessary is a force sufficient to overcome the static bottom friction and cohesion of the sedimentary particles. If there is sufficient turbulence to lift a particle momentarily, then any resultant force acting in a constant direction, for example the component of gravity down the slopes, would be sufficient for the transportation of the particle. Turbulent motion may be produced by waves and drift currents provided the sea-floor is hydro-dynamically rough, but as these are effective on the sea-floor only in relatively shallow water, probably less than 183 m. (100 fm.) in depth, it is improbable that it can be assigned to this cause. Tsunamis or tidal waves, however, in view of their great wave length and their consequential small decrease of velocity toward the bottom, may be an effective sorting agent on elevations (Shepard, F. P., 1941, p. 1881 ; Macdonald, G. A. and others, 1947). Convection currents, due to the inclination of equal density surfaces, compared with the horizontal within the sea, are generally weak, but nevertheless will transport material until the current vanishes. It is clear that there can be practically no horizontal current in the deeper parts of basins because the water is confined by the periphery of the basin and can in consequence only move vertically, i.e., against the forces arising from the stability of the water. Currents associated with internal waves may attain, however, appreciable velocities toward the bottom (Sverdrup, H. U., and others, 1942, p. 590), and finally there are large moving eddies with vertical axes (Revelle, R., 1940, p. 114). The basic concept concerning transportation along the deep-sea floor is that, where there is turbulence, a current may carry a load of suspended particles provided that the downward transport due to the settling of the particles is equal to the upward transport produced by eddy diffusion. Some idea of the equivalent diameter of the particles in suspension can be obtained by assuming that the sea-floor is hydrodynamically rough, and it has been shown that, with a bottom current of 10 cm. sec. 2 m. above the bottom, very fine sand, silt and clay would be in suspension near to the bottom (Sverdrup, H. U. and others, 1942, p. 965). Mechanisms therefore exist which will sweep the finer material from submarine elevations and deposit it in basins. It is interesting to point out that, off the Californian coast, there is a close agreement between rock bottom and currents (Revelle, R. and Shepard, F. P., 1939, p. 277).

Very few observations have been made on currents immediately above the deep-sea floor, and so far as the authors are aware the only available measurements are those made off the Californian coast (Shepard, F. P., 1941, p. 1882 ; Revelle, R., 1940, p. 114). Currents were measured down to depths of 1829 m. (1000 fm.) by means of current meters attached to a tripod. In practically all localities on submarine elevations the currents were extremely variable, but sometimes attained sufficient velocities for transporting fine material. In one locality the current had sufficient velocity to roll gravel (Hjulström, F., 1939, p. 10). It should, however, be noted that although the by-passing of sediments on elevations can be explained, there is no direct relation between the texture of the sediment and the strength of the current, e.g., the strongest current was found on the slopes off the Palos Verdes Hills where the bottom deposit is mud. It is, however, possible that the cohesion of clay particles when once deposited, would inhibit their re-suspension even with rapid currents.

Morphology, as previously mentioned, affects the chemical composition of deep-sea sediments, especially in basins. Free intercommunication between the basin and the open sea, or between one basin and another, takes place above the sill depth, and in consequence the temperature, as well as salinity, will, below this depth, be relatively uniform and will approximate to the properties of the water at the sill depth. Potential temperature, i.e., the temperature which a water sample would attain if raised adiabatically to the sea surface (Helland-Hansen, B., 1912) remains practically constant below the sill depth, and has been used as a means of determining its depth (Wüst, G., 1940, p. 6), especially in places where there is little interchange with the open sea. The peculiar hydrological conditions in basins have been described by recent authors (Fleming, R. H. and Revelle, R., 1939, pp. 95–102 ; Sverdrup, H. U. and others, 1942, pp. 147–50), and it has been shown that the deeper water in basins can only be replaced by turbulent or convective mixing, or by replacement with heavier waters which flow over the sill. Convective mixing cannot take place if density stratification exists and turbulence will be inhibited. In deep basins where the bottom water is only occasionally renewed, and in which organic matter is deposited from the surface layers, processes of oxidation will largely use up the available supply of oxygen, and hydrogen sulphide will in consequence be formed in the mud. The pH of the deep water will be lowered, and the bottom waters will be largely sterile apart from anaerobic bacteria. Black mud or blue mud will be deposited with a high organic carbon content. There will be a tendency in view of the low pH for ferric oxide particles deposited from the oxygenated upper waters to be redissolved, and the iron content of the bottom water will increase. In this connection Cooper (1948, p. 280) has shown that there is a concentration of iron in the surface film and in the layers of water near to the bottom, whilst in lakes there is a high concentration of iron in the de-oxygenated hypolimmion (Müller, E., 1938 ; Einsele, W. and Vetter, H., 1938). It has been demonstrated for example (Mortimer, C. H., 1941, p. 290) that ferrous iron appears in the bottom layers of Esthwaite Water when the oxygen has disappeared and the redox (oxidation-reduction) potential falls to $E_7=0.18$ V.

In basins where there is a slow renewal of the deep water there will be a tendency towards calcium carbonate saturation, and highly calcareous sediments will in general accumulate. Submarine volcanic activity may in these cases through acid emanations influence the carbonate content of the sediments.

Submarine elevations may obstruct or hinder the bottom flow of highly oxygenated polar water, and blue mud may occur in such regions instead of the usual red clay. A good example of this is in the Weber Deep, in the East Indies, where in spite of a depth of 7440 m. (4068 fm.) the deposit is blue mud (Neeb, G. A., 1943, Plate I). The reason for the absence of red colour is due to the obstruction of the cold bottom water by a sill at a depth of 3130 m. (1711 fm.). In the East Indies the sills influence considerably the nature of the sediment, e.g., the calcium carbonate content (Umbgrove, J. H. F., 1949, p. 17).

Little is known about the hydrological conditions in oceanic basins below 4000 m. (2187 fm.), and when more information is forthcoming about the physical and chemical properties of the water immediately above the floor it may be possible to work out the details of the chemical interchange between the deep-sea sediments and the bottom water. It may then be possible, for example, to formulate a satisfactory theory concerning the origin of manganese nodules and glauconite, and to find the reason for the low potash content of sea-water.

Sea-water contains carbon dioxide both as bicarbonate and carbonate ions, as undissociated molecules of CO_2 and as carbonic acid all in equilibrium with each other and with the hydrogen ions present. This system largely controls the solubility of calcium carbonate in sea-water (Gripenberg, S., 1937 ; Harvey, H. W., 1945, pp. 52–73 ; Revelle, R., 1934 ; Sverdrup, H. U., and others, 1942, pp. 195–210). The most important factor controlling the solubility of calcium carbonate is the CO_2 content of sea-water, which is mainly dependent on the nature and amount of biological activity. The order of importance of the other factors is temperature, salinity and hydrostatic pressure. Calcium carbonate is in consequence most likely to dissolve in bottom waters which have originated from high latitudes, and in which the CO_2 has been increased by oxidation of organic debris. In consequence when there is a large organic population as a result of upwelling or diverging currents there is reason to believe that the carbonate content of the sediment will be low, provided the other factors remain constant. Many other factors may, of course, influence the carbonate content of deep-sea deposits, e.g., the rate of deposition of the non-carbonate component of the deposit. Morphology may play here an important role, because the finer and frequently non-calcareous components will tend to accumulate in basins whilst the calcareous sands will predominate on elevations. It is of some biological significance, in connection with the solubility of calcium carbonate, to note that the absence of a thinly walled calcareous organism from deep-sea deposits does not necessarily imply that it had no existence in that region.

7. DEEP-SEA CORING AND ITS IMPORTANCE IN RELATION TO PAST OCEANIC HISTORY

Only recently have satisfactory methods been developed for obtaining long cores from the deep-sea (Kullenberg, B., 1947). The problems to be solved are essentially to give the coring tube sufficient energy to ensure a reasonable depth of penetration, and to overcome the friction on the internal wall of the tube, which in simple tubes is sufficient after a small depth of penetration to prevent any more sediment entering the mouth. Many coring devices obtain their energy from weights attached to the top of a coring tube directly attached to the hydrographic wire. The best-known early example of this is the Baillie sounding machine, which is essentially a development of Brooke's sounding apparatus ; it was used on the *Challenger* Expedition and is said to have brought up cores 1ft. 6in.–2ft. in length (Murray, J., and Reynard, A. F., 1891, pp. 3–4). The *Meteor* Expedition (Correns, C. W., 1935, pp. 1–3), the *Snellius* Expedition (Kuenen, Ph.H., 1942, p. 4) and the John Murray Expedition (Sewell, R. B. S., 1935, p. 10) used simple gravitational corers, but the cores were normally less than 2 m. long. Improvements to the simple gravity apparatus have been made at La Jolla Oceanographical Institute and cores up to 4.8 m. have been obtained (Emery, K. O. and Dietz, R. S., 1941, p. 1691). In an attempt to improve the depth of penetration Piggot (1936) introduced for the driving energy an explosive charge. Cores were obtained by the *Lord Kelvin* from the North Atlantic (Bramlette, M. N. and Bradley, W. H., 1942) by means of this new device, but the longest core obtained was 2.9 m. Because of the operational danger and because larger cores can be obtained by a simple gravity apparatus, this device is little used. The introduction of the free-fall device (Hvorslev, M. J. and Stetson, H. C., 1946) made greater penetration possible. The principle of the device is to give the coring tube a free fall a few meters above the bottom and hence to increase its potential and kinetic energy. The free fall is achieved by means of a pilot weight and release mechanism which allows the corer to fall freely through the water from a predetermined distance above the sea-bottom.

The Kullenberg piston core sampler, used aboard the *Albatross* by the Swedish Deep-Sea Expedition, 1947–8, obtains its driving energy by means of a free-fall device, and overcomes the difficulty of internal friction by a stationary piston placed inside the coring tube. The principle of this device is that, as the coring tube penetrates the bottom, the internal friction will exert a downward pull on the core which is overcome by the hydrostatic pressure of water, because the piston remains stationary with reference to the deep-sea floor and prevents a vacuum from being created between the piston and the top of the core. The technique has been developed by Dr. Kullenberg, and he has shown that, provided the winch is run at a predetermined rate and is stopped immediately the longitudinal elastic wave reaches the ship, the piston will remain stationary. With the use of this apparatus cores 15 m. or longer have been obtained during the Swedish Deep-Sea Expedition, and it is known that Dr. Kullenberg has plans for still longer cores.

Deep-sea cores, if taken in favourable situations, may reveal important geological and climatological events in oceanic history. How far these changes can be traced into the past depends not only on the core length but also on the rate of sedimentation, which differs both with the nature of the deposit, and also with location and time. It is generally believed, however, that red clay accumulates the slowest and globigerina ooze slightly more rapidly. It therefore seems possible, assuming an average rate of sedimentation of 1 cm. in 1000 years, that a 15 m. core would extend into late Pliocene deposits.

Events in ocean history may be revealed through sedimentary (chemical textural and mineralogical) or biological changes. It is convenient to consider first of all the events which can be recognised by significant sedimentary change, and to reserve for a later section the information derived from detailed foraminiferal investigations. Chemical changes in a core are essentially the result of one or more of the following four causes :—first, changes related to the content of the biological component ; secondly, those related to the amount of the non-biological component ; thirdly, those related to the properties of the sea-water in contact with or above the sediment ; and, fourthly, changes related to morphology. The properties of the sea-water may change owing to some fundamental oceanographical reason (e.g., changed circulation and properties of the sea-water during the Pleistocene ice age), or on account of some diastrophic event which locally effects a considerable morphological change. As many of these causes are to some extent interdependent, there is much uncertainty about the fundamental reason for a chemical change. It is possible, however, that this difficulty may be partially overcome if future investigations prove that there is some unique property of the non-biological component which has remained essentially constant in any sedimentary type from a single oceanographical area. It would then be possible to eliminate changes due to variations in the biological components. It is clear that the elements suitable for investigation are those which are both absent or sparingly soluble in sea-water, and are also likely to be reasonably constant in the non-biological portion of a sedimentary type. Work by one of the authors (J.D.H.W.) suggests that TiO_2, which has only been detected spectrographically in sea-water, may be a suitable element in the case of globigerina ooze and red clay from the deep-sea floor in the Arabian and Somali Basins.

Although it would be inappropriate to discuss in detail the chemical changes which have been revealed by recent work on cores it is perhaps important to note some of the major variations in so far as they are important in revealing past history. Radioactive changes will, however, be reserved for special consideration. Calcium carbonate is one of the most variable components in deep-sea deposits, and much attention has been given to its regional and vertical variation (Correns, C. W., 1937, pp. 205–19 ; Murray, J. and Reynard, A. F., 1891, pp. 34–147 ; Neeb, G. A., 1943, pp. 200–11 ; Pratje, O., 1939 ; Revelle, R., 1944, pp. 99–126 ; Trask, P. D., 1937 ; Wiseman, J. D. H. and Bennett, H., 1940, pp. 202–3). Some of the factors governing the calcium carbonate content have been discussed previously, and it follows that if globigerina ooze changes to red clay this alteration is a reflection of changed physical and chemical conditions, as well as in the supply of the calcareous and non-calcareous components of the sediments. On a basis of foraminiferal content the superposition of globigerina ooze on red clay is in some instances related to an increase in surface temperature (Pratje, O., 1939, p. 81 ; Phillipi, E., 1910, p. 591), as is also the superposition of globigerina ooze over siliceous diatom ooze or glacial marine deposits in the Southern Ocean. Phillipi (1908) was the first to suggest that the downward decrease of calcium carbonate frequently observed in cores reflects a climatic control. It is of some interest to note that oscillations in the Antarctic Convergence (the region where there is a sudden increase of surface temperature and where the surface water sinks to form the Antarctic Intermediate water) during a glacial period could doubtless be detected by a series of cores taken in a north–south direction. During the glacial periods the most northerly limit of the Antarctic Convergence would be marked by a layer of diatom ooze below globigerina ooze, whilst the most southerly limit during an interglacial would be characterised by the superposition of thick glacial marine deposits over diatom ooze.

Some cores show a distinct variation in the ratio of ferric to ferrous iron, or in the total iron content, and this is in some cases connected with differing hydrological conditions. The oxygen deficit, as measured by the oxygen absorbed after the addition of mercuric chloride to kill living organisms and to inactivate enzymes, is related to the reduced state of the iron and manganese, as well as to the presence of auto-oxidisable organic substances. Changes in the state of oxidation can normally be detected by a change in colour, as a greyish-blue or black colour usually indicates the presence of hydrotroilite (ferrous sulphide), and an oxidising environment is indicated by a buff or brown colour. Colour changes in deep-sea sediments are useful environmental indicators, and they should be recorded according to some standard scale, when the sediment is moist, as the colours are then most intense.

The organic content in cores measured by the organic carbon and nitrogen (Arrhenius, G., 1948, pp. 30–3 ; Wiseman, J. D. H., 1940, pp. 214–16) fluctuates with depth. It may either decrease, increase or oscillate with depth. These fluctuations may be explained because organic matter at any depth in a core is a function of several factors and does not solely depend on the productivity of the area where the sediment was deposited. The organic content may be influenced in opposite directions by two other factors, the first being the decrease in depth caused by time of burial and biological considerations, and the second an increase with depth due to a decrease in the rate of sedimentation.

Phosphate content has been found to change with depth in a core, and it has been suggested that because the fluctuations between different layers are large, they may eventually be used in cores for purposes of correlation (Arrhenius, G., 1948a, pp. 26–9). Very little work has been done on the chemistry of the minor elements found in cores.

Changes in texture of a core with depth are important in so far as they can be related to environment. Diastrophism, morphology, climatology, including oceanic currents and vulcanism, may influence texture. Some of the ways in which morphology may influence texture have been previously described. Climatology in so far as it effects the physical and chemical properties of currents, and the supply of glacial or wind-blown detritus, has a direct relation to texture. In the cores collected by Dr. C. S. Piggot from the North Atlantic west of the Mid-Atlantic Ridge it has been shown (Bramlette, M. N. and Bradley, W. H., 1942, p. 4) that there are four layers of glacial marine deposits characterised by an increased content of sand, granules and pebbles. The glacial marine deposits interdigitate with globigerina ooze and it is assumed that they taper away southward and thicken northward to unite as a continuous deposit. Bramlette and Bradley suggested that the four glacial marine zones represented substages of the Wisconsin stage, and it is of interest to recall that all the four glacial zones occur within the last 62,000 years according to radioactive measurements (Piggot, C. S. and Urry, W. D., 1942, p. 1196). More information about the grain-size characteristics (median diameter, skewness, degree of sorting) of glacial marine deposits as well as their equivalents outside the glaciated region, might prove to be of considerable use in marine chronology. A start has been made for the Arctic (Stetson, H. C., 1933, pp. 32–3) where it has been shown that the statistical constants indicate a closer relationship with shallow-water clays deposited near to the shore than with deep-sea clays. In this connection it should be noted that no icebergs are formed from glaciers in the Arctic Basin (north of Siberia) and during the spring the surface of the ice along the Siberian continental shelf is flooded by river deposits. When the floes break up this material is eventually deposited on the deep-sea floor. It is clear that in the Davis Strait region (Trask, P. D., 1932a, p. 78) owing to the degree of sorting, currents play an important part. In the Southern Ocean the glacial marine deposits are essentially tillites (Stetson, H. C., 1937, p. 63) and have similar characteristics to those laid down on land. They are composed of a heterogeneous mixture of coarse and fine particles, and are in consequence unsorted. As a result material deposited in front of the ice barrier is frequently the same as that laid down 300 miles seaward.

Change in the texture of a sedimentary type with depth may also be an indication of a climatological change. For example, as mentioned earlier, globigerina ooze may, owing to a climate change, be superimposed on a red clay (Correns, C. W., 1937, p. 203). Some textural changes are related to an influx of minerals blown off loosely consolidated surface deposits (Radczweski, O. E., 1937, p. 276). Those associated with vulcanism frequently produce distinct layers, and mask in certain areas textural changes related to bottom configuration. For example, in the Molukken Sea, the texture of the sediments is largely determined by the composition of the volcanic ash originating from the volcanoes Roeang and Halmaheira.

In favourable circumstances the geological evolution of the oceans may be shown by mineralogical changes. For example, glacial marine deposits are normally characterised by an abundant supply of fresh and angular minerals. The occurrence of volcanic ash zones in the North Atlantic cores was of considerable use in correlation (Bramlette, M. N. and Bradley, W. H., 1942, pp. 2–3). It was possible by this means to correlate the upper and lower volcanic ash zones from cores collected west of the Mid-Atlantic Ridge. The source of the volcanic shards is, however, unknown ; but Bramlette and Bradley suggested that they possibly originated from some of the northern volcanic islands. Correlations can also be effected by a detailed mineralogical examination. The East Indies is particularly suitable for investigation on these lines (Neeb, G. A., 1943) for not only have there been recent volcanic outbursts, but the mineralogical characters of the ash derived from these outbursts are in some cases well known (Esenwein, P., 1930 ; Wichmann, A., 1902 and 1921). It is of particular interest to note that a core from the Celebes Basin revealed Tambora ash (50–200 μ diameter) erupted in 1815, at a depth of 38–42 cm. The ash becomes finer in an upward direction and is admixed with clay. The ash is still being deposited in oceanographical conditions which are not clear (Kuenen, Ph.H., 1942, pp. 36–40). From the thickness of deposits above ash zones of known date it has been possible to estimate that the rate of sedimentation for the non-volcanic terrigenous matter is 75 cm. per thousand years in the East Indies (Neeb, G. A., 1943, p. 237). The figure for the East Indies is, therefore, about 50 times as large as that for globigerina ooze from the open ocean (Schott, W., 1938).

Great difficulty is experienced in some cases in establishing chronology, e.g., the long cores obtained by the Kullenberg piston corer in the Tyrrhenian Sea 100–200 km. west of Mt. Vesuvius (Mellis, O., 1948, p. 67). Here the pyroclastic zones could not be identified with corresponding ash layers on land, doubtless because volcanic ashes may undergo considerable atmospheric differentiation, thereby achieving a rough mineral and grain size separation. Further differentiation may take place as a result of capillary action on the sea surface, as well as through different rates of sinking.

There is little information about the exact nature of the clay minerals present in deep-sea deposits (Mehmel, M., 1939 ; Revelle, R., 1944, p. 81), but with the recent developments in clay mineralogy it should be possible in the future to give more positive identifications. It may then be possible to establish some relationship between environment and the nature of the clay mineral. Since this paper went to press an important work on the clay mineral composition of deep-sea sediments has appeared (Grim, R. E. and others, 1949).

8. RADIOACTIVITY OF MARINE SEDIMENTS AND OF OCEAN WATER AND ITS USE IN MARINE CHRONOLOGY

The occurrence of radium in deep-sea deposits was first demonstrated by Joly (1908) on samples collected by H.M.S. *Challenger* and U.S.F.C. *Albatross*. The average radium content found for 12 samples was 17.8×10^{-12} g. per g. It is generally agreed that these early determinations are too high ; a conclusion which is supported by the lower contents obtained by Pettersson (1930, p. 40) for two of the same *Challenger* samples, as well as the lower average 10.96 $\times 10^{-12}$ g. per g. Additional support is given to this conclusion by the average (6.52×10^{-12} g. per g.) for 28 *Carnegie* samples collected with one exception from the Pacific (Piggot, C. S., 1933, p. 231).

Many recent measurements have been reported (Evans, R. D. and Kip, R. F., 1938 ; Piggot, C. S. and Urry, W. D., 1939, 1942a ; Urry, W. D. and Piggot, C. S., 1942 ; Pettersson, H., 1948b). High values have been found in some of the samples from the North Pacific investigated by Hanguchi (1938), whilst the most recent measurements are those on cores collected by the U.S. Navy Antarctic Expedition 1946-7 (Urry, W. D., 1949).

In contrast with the relatively high values found in pelagic deposits, shallow water terrigenous deposits have generally lower values. The average radium content in deposits north of Vancouver Island is 0.24 x 10^{-12} g. per g., whilst in the Puget Sound the average content was 0.37 x 10^{-12} g. per g. (Utterback, C. L. and Sanderman, L. A., 1938, p. 190). In deposits from the shallow waters of the North Pacific, the average radium content is 0.74 x 10^{-12} g. per g. (Sanderman, L. A. and Utterback, C. L., 1941). It would seem that the radium content of inshore samples is largely determined by the content in the land area from which the sediment is derived, and it is of interest to note that the average value (0.64 x 10^{-12} g. per g.) for sediments collected near the mouth of the Skenna River is practically the same as the average (0.63 x 10^{-12} g. per g.) for representative rocks from this area (Sanderman, L. A. and Utterback, C. L., 1941, p. 137). The high values found in some of the duplicate samples in cores from the Tyrrhenian Sea have been ascribed to some radioactive mineral which happened to be deposited in one of the samples (Pettersson, H., 1948b, p. 91).

Many determinations have been made on the radium content of sea-water. The early investigators obtained relatively high values, 9–10 x 10^{-13} g. per litre (Eve, A. S., 1909, p. 107 ; Satterly, J., 1911, p. 342) whilst the later investigators obtained values about 1 x 10^{-13} g. per litre (Evans, R. D., Kip, A. F. and Moberg, E. G., 1938b, p. 247 ; Pettersson, H. and Rona, E., 1939, p. 27 ; Pettersson, H., 1949a, p. 469). As the amount of uranium present in sea-water is about 1.5 x 10^{-6} g. per litre (Karlik, B., 1939, p. 12 ; Pettersson, H., 1949a, p. 419) the radium in equilibrium with it should be 5.1 x 10^{-13} g. per litre, as the ratio of Ra/U in equilibrium is 3.4 x 10^{-7}. This theoretical amount of radium is five to seven times as much as that found in sea-water, and in consequence there is in sea-water a deficit of radium as compared with its grandparent uranium.

It is significant that a complementary relation occurs in the upper layers of deep-sea cores, where there is more radium present than there should be if it is in equilibrium with the original uranium content of the deposit. For example, in a core from the Cayman Trough the average uranium content is 0.84 x 10^{-6} g. per g. in samples taken from three depths (Urry, W. D., 1941, p. 197). This is roughly one quarter of the amount required to maintain equilibrium with the average radium content of 1.14 x 10^{-12} g. per g. found in the core (Piggot, C. S. and Urry, W. D., 1942a, p. 4).

It is concluded that radium or its parent ionium is abstracted from sea-water, on account of its excess in deep-sea deposits and its deficit in sea-water as compared with uranium. Pettersson and Rona (1939, p. 34) have suggested that ionium is largely abstracted by precipitation from the sea along with ferric iron. Biological extraction has been suggested by some authors (Evans, R. D., Kip, A. F. and Moberg, E. G., 1938, pp. 235–7 ; Revelle, R., 1944,

p. 65) but is unlikely as phytoplankton can only remove in a year a few per cent of the radium present in their habitat. Nor is it possible to account for the removal as a cumulative effect in view of vertical oceanic circulation (Pettersson, H. and Rona, E., 1939, p. 33). It is possible that some of the radium present in sea-water is absorbed by manganese (Koczy, F. F., 1949, p. 239), and it is of some interest to recall Revelle's conclusion (1944, p. 65) that the distribution of manganese dioxide and radium show an inverse relation. It is possible that much of radium present in the sea-water immediately above the deep-sea floor is in some cases absorbed by manganese nodules, and support is given to this idea by the low radium content at the top of a red clay core from the Arabian Basin and its high content in the peripheral layers of manganese nodules from the same station.

For measuring recent intervals of time in the Pleistocene, properties of the radioelements must be used which are independent of the production of stable end-products, because these are not applicable to the immediate past. If radium is, for example, separated from its parents ionium and uranium, its concentration with time would decrease exponentially with a half life of 1700 years. It would then be possible to estimate time by direct radium determinations. In manganese nodules the radium is largely unsupported, and with a knowledge of the radium distribution it has been possible to calculate that the rate of radial growth is about 1 mm. in 1000 years (Pettersson, H., 1943, p. 31). In view, however, of the recent discovery by one of the authors (J. D. H. W.) of a microcellular structure in manganese nodules, conclusions about the rate of sedimentation of red clay from the radioactive distribution in manganese nodules would seem questionable.

Deep-sea cores present the opportunity of following the concentrations of radioelements in the U-238 series as they change with time. It would seem that in general uranium, ionium and radium are being deposited in deep-sea sediments in concentrations which differ considerably from the fixed ratios in radioactive equilibrium, and there is in consequence a complicated variation of radium content with depth below the deep-sea floor surface.

It is generally concluded that there is less radium in the uppermost layers of a core than is in equilibrium with the ionium, and more ionium than is in equilibrium with the uranium. In consequence the radium content increases rapidly below the surface, unless the rate of deposition is high, but below the depth corresponding with the time interval necessary to establish equilibrium with ionium, it diminishes as the ionium content decreases. Finally, after an interval of nearly half a million years, the radium content remains almost constant, because the three elements of the U-238 series are in radioactive equilibrium (Piggot, C. S. and Urry, W. D., 1942, p. 1191 ; Urry, W., 1949, p. 258).

If it is assumed that a constant concentration of elements in the U-238 series have been deposited, it is possible to give quantitative equations (Urry, W. D., 1942) governing the growth and decay of these elements with time. In this way it is possible to analyse the curve obtained for the radium content with depth, and to assign dates to any desired depth. It should be noted that in the analysis of radioactive measurements for the purpose of finding depth-time relations it is important to express the radium content on a volume basis. This can be derived from the water content or by indirect methods (Piggot, C. S. and Urry, W. D., 1942a, p. 6).

A general idea of the rate of deposition can be obtained from the depth at which the radium maximum occurs, because the time required to establish the maximum radium content will be between 7000–8000 years, irrespective of the initial concentration of radium and ionium (Urry, W. D., 1942). A second obvious point on the time scale occurs where the radium content becomes independent of depth, because this will occur between 400,000–500,000 years.

The Urry technique for obtaining time-depth relations in the latter half of the Pleistocene is most promising, but the technique should, of course, be used only in those cores, or portions of the core, where there has been no terrigenous admixture, or an influx of volcanic material or coarse glacial deposits. It is, therefore, unlikely that the technique will be suitable for deposits on or near to the continental shelf, and will in all probability have to be confined to deposits formed in oxidising environments.

The applications of this technique are important to investigations dealing with changing geological, climatological, geophysical and oceanographical conditions in the immediate past. It has been previously noted that it is possible to plot to some extent the isochronic surfaces in the North Atlantic from ash and glacial zones. It is of great interest to note that the bottom of the top ash zone was formed 12,000 years ago, and that all four zones of glacial marine deposits occur within the last 62,000 years (Piggot, C. S. and Urry, W. D., 1942). It is also possible to determine rates of sedimentation and to show how the rate varies with time and place. It should also be possible to assign ages to climatic oscillations as determined by foraminiferal analysis during the latter half of the Pleistocene and in consequence to facilitate the correlation of Pleistocene chronology.

9. THE SIGNIFICANCE OF PLANKTONIC FORAMINIFERA AS TEMPERATURE-INDICATORS IN CORES

(a) Historical Survey

The realisation that foraminifera were of importance in the interpretation of past climatic conditions was first put forward by Phillipi (1910, p. 568). More recent work since the development of improved coring apparatus has completely justified his theory. Recently, several authors have attempted to interpret ocean temperature changes of the past from successive core samples, notably Cushman and Henbest (1942) for the trans-Atlantic cores taken on board the cable ship *Lord Kelvin*, Schott (1935) for the equatorial Atlantic, Stubbings (1939) for the Arabian Sea and Phleger (1947 and 1948) for the Tyrrhenian and Caribbean Seas. The last core is of particular interest. It was procured by the Swedish Deep-Sea Expedition 1947-8 with the Kullenberg corer, and is the first long deep-sea core (15.4 m.) to be studied.

From a study of the cores collected in southern latitudes it should be possible to solve the problem of the contemporaneity of the glaciation in the northern and southern hemispheres (see sect. 11, p. 69), and in this connection the cores collected by Dr. J. L. Hough on the U.S. Navy Antarctic Expedition of 1946-7 should be of the greatest importance.

Phleger (1948) by means of a systematic study of 75 core samples has constructed a climatological depth-curve. This is reproduced in a recent article (Ovey, C. D., 1949a) and the most probable interpretation according to Phleger in terms of the American main glaciation is given in the right-hand column of the figure (*ibid.* p. 230). Phleger has, however, suggested by analogy with work on other cores (Schott, W., 1935 ; Phleger, R. B. and Hamilton, W. A., 1946 ; and Piggot, C. S. and Urry, W. D., 1942), that the rate of sedimentation of globigerina ooze at this locality in the Caribbean is about 1 cm. per 1000 years, thus making the whole length of 1540 cm. equivalent to a period of approximately 1,500,000 years. On this assumption, if the length of the core represents that part of the Pleistocene from the beginning of the Günz, then its duration is about twice as long as that given by Fuchs and Paterson (1947, p. 329), and approximately three times that given by Köppen, Zeuner, Penck and Brückner (Brooks, C. E. P., 1949, pp. 106–7). By applying, however, the results of the test described below to Phleger's figures of the occurrence of species in the Caribbean core, it seems likely that only one glacial and one interglacial period are represented, thus making the rate of sedimentation much more rapid.

(b) Test of the validity of Planktonic Foraminifera as Temperature-Indicators

In order to demonstrate whether planktonic foraminifera are useful as temperature-indicators, samples of deep-sea deposits were investigated from nine widely separated localities (Fig. 1). From the washings, a thousand specimens or a little over were counted and recorded under the appropriate species (Table II, p. 60). Specimens of the approximate diameter of less than 125μ were ignored

improved coring apparatus has completely justified his theory. Recently, several authors have attempted to interpret ocean temperature changes of the past from successive core samples, notably Cushman and Henbest (1942) for the trans-Atlantic cores taken on board the cable ship *Lord Kelvin*, Schott (1935) for the equatorial Atlantic, Stubbings (1939) for the Arabian Sea and Phleger (1947 and 1948) for the Tyrrhenian and Caribbean Seas. The last core is of particular interest. It was procured by the Swedish Deep-Sea Expedition 1947-8 with the Kullenberg corer, and is the first long deep-sea core (15.4 m.) to be studied.

From a study of the cores collected in southern latitudes it should be possible to solve the problem of the contemporaneity of the glaciation in the northern and southern hemispheres (see sect. 11, p. 69), and in this connection the cores collected by Dr. J. L. Hough on the U.S. Navy Antarctic Expedition of 1946-7 should be of the greatest importance.

Phleger (1948) by means of a systematic study of 75 core samples has constructed a climatological depth-curve. This is reproduced in a recent article (Ovey, C. D., 1949a) and the most probable interpretation according to Phleger in terms of the American main glaciation is given in the right-hand column of the figure (*ibid.* p. 230). Phleger has, however, suggested by analogy with work on other cores (Schott, W., 1935 ; Phleger, R. B. and Hamilton, W. A., 1946 ; and Piggot, C. S. and Urry, W. D., 1942), that the rate of sedimentation of globigerina ooze at this locality in the Caribbean is about 1 cm. per 1000 years, thus making the whole length of 1540 cm. equivalent to a period of approximately 1,500,000 years. On this assumption, if the length of the core represents that part of the Pleistocene from the beginning of the Günz, then its duration is about twice as long as that given by Fuchs and Paterson (1947, p. 329), and approximately three times that given by Köppen, Zeuner, Penck and Brückner (Brooks, C. E. P., 1949, pp. 106–7). By applying, however, the results of the test described below to Phleger's figures of the occurrence of species in the Caribbean core, it seems likely that only one glacial and one interglacial period are represented, thus making the rate of sedimentation much more rapid.

(b) Test of the validity of Planktonic Foraminifera as Temperature-Indicators

In order to demonstrate whether planktonic foraminifera are useful as temperature-indicators, samples of deep-sea deposits were investigated from nine widely separated localities (Fig. 1). From the washings, a thousand specimens or a little over were counted and recorded under the appropriate species (Table II, p. 60). Specimens of the approximate diameter of less than 125μ were ignored

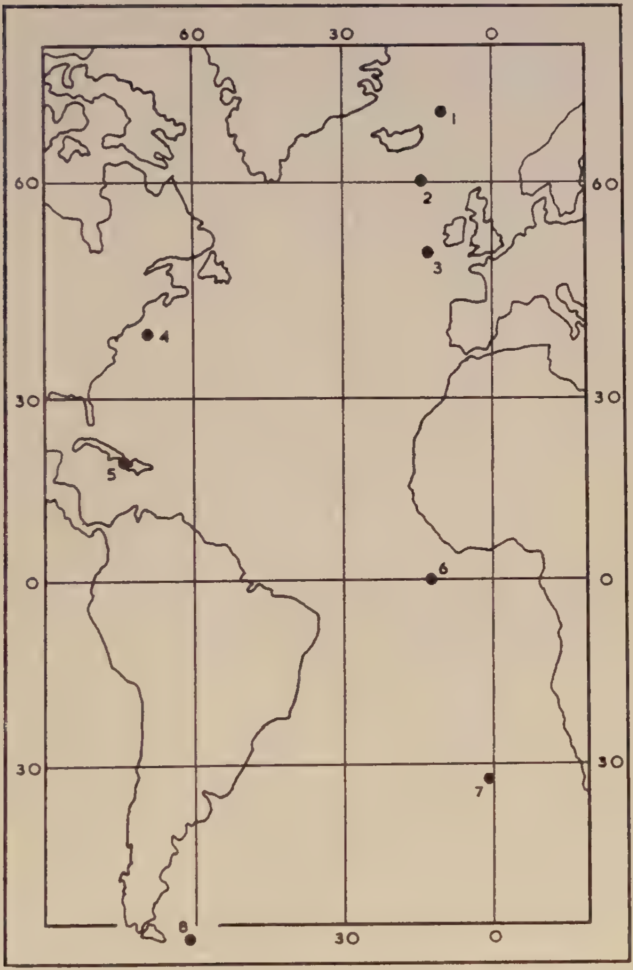


FIG. 1.—Map of the Atlantic Ocean indicating position of eight of the nine samples used. The ninth sample was taken in the Ross Sea south of the Antarctic Convergence at 66°38′ S.–178°47′ W.

owing to the extreme risk of misidentification in juvenile forms. The geological range of the species used is shown in Table I. These ranges are based on a large number of records and they are somewhat tentative.

Table II shows the actual number of specimens of each species counted in each sample. An attempt is made from the figures to

TABLE II. NUMBER OF SPECIMENS OF EACH SPECIES OBSERVED IN THE SAMPLES

SPECIES / POSITION OF SAMPLES		COLD		TEMPERATE						WARM											TOTAL NUMBER OF SPECIMENS COUNTED
		Globigerina dutertrei	,, pachyderma	,, bulloides	,, inflata	Globorotalia crassula	,, canariensis	,, truncatulinoides	,, hirsuta	,, scitula	Globigerina dubia	Sphaeroidinella dehiscens	Orbulina universa	Globigerinella aequilateralis	Globigerinoides rubra	,, sacculifera	,, conglobata	Globorotalia menardii	,, tumida	Pulleniatina obliquiloculata	
1	69°2'N 9°26'W	125	762	153	3																1043
2	[illegible]0°30'N 16°11'W	38	718	181	53		1	7	1		1										1000
3	51°22½'N 12°38'W	1	9	329	631	5	3	26	1	2	74		18	3	1						1107
4	39°26'N 68°3½'W	1	11	247	470		3	10	1	1	130		12	9	5	2	18	74	18	12	1024
5	19°51'N 74°26'W		1	10	7	1	1	31	1	2	90	8	274	156	204	291	23	83	12	2	1197
6	0°1'6"S 15°16'W			2	8	10		9			96	2	67	65	185	274	2	169	22	96	1007
7	32°31'S 1°32½'W	1	13	220	408	22	77	153	17	2	7	9	33	14	12	1	10	1		1	1000
8	55°49'S 56°18'W	121	114	293	429	50															1007
9	66°38'S 178°47'W	963	137	11	2																1113

arrange the species listed in this table in order of relative tolerance to temperature conditions, although it is obvious that there is nothing to choose between certain of the species shown.

The result of adding the numbers of those species listed in Table II, under the separate headings "Cold," "Temperate" and "Warm," and converting them into percentages of the total number counted in each sample is shown by histograms in Table III.

It is fully realised that these nine samples cannot by themselves show any hard and fast reflection of specific temperature limits and it is not possible to know exactly what thickness of the bottom sediment was removed from the ocean bed surface when each sample was obtained. Several thousand years of sediment may have been brought up, so the fauna in each cannot be a direct reflection of surface water conditions. It will also be necessary to work out the distribution of as many individual species as possible and to estimate, from charts of maximum and minimum monthly mean sea surface temperatures, such as those shown by Hutchins and Scharff (1947), the temperature limits and tolerance of each species. It might then be possible to produce distribution maps for each species on the lines of Hutchins (1947), who studied by this method the temperature limits of the species *Mytilus edulis*, *Balanus balanoides* and the hydroid *Syncoryne eximia*. Admittedly these three creatures are benthonic littoral forms, but the procedure should be similar in the case of planktonic animals. In the same paper it is noted, however, that these organisms can live for a time outside normal temperature limits but cannot breed except within certain more restricted limits. In his study of the foraminifer *Elphidium crispum* (Linn.) at Plymouth, Myers (1943, p. 442, Fig. 2) shows that the species breeds sexually in March and April and asexually in April and May and again in the latter part of September. If the same should also apply to planktonic species of foraminifera and involve temperature ranges, it would appear that the breeding temperature —i.e., the mean limits of the breeding months—would be the most important control of their survival, and not the extreme temperature ranges. The greatest ranges are those found off the continental shelf of America (sample No. 4) and Japan, where temperature gradients are steep and seasonal variation is considerable (see McDonald, W. F., 1944, maps 127–30).

Both Schott (1935) and Phleger (1945) have found that foraminifera in the living state exist to at least 1000 m. (547 fm.) but are generally most abundant in the region of 70 to 100 m. (38–55 fm.), although in some net samples the greatest abundance has been found in the neighbourhood of 1000 m. (547 fm.). More recently it has been stated in an article by Phleger (1949, p. 1457) that recent evidence shows that planktonic species may live in abundance to a depth of 2000 m. (1094 fm.). It is difficult to reconcile this conclusion with the results of the investigation described in this paper, unless there is a

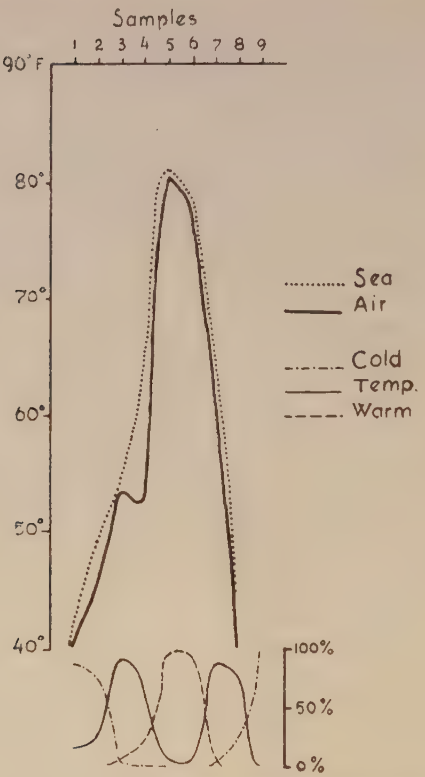


FIG. 2.—Graphical diagram to demonstrate relationship between the distribution of cold, temperate and warm planktonic foraminifera in the nine samples examined, and air and sea-surface temperatures.

remarkable concentration of foraminifera in the surface layers as compared with depth. It is not surprising, in view of the decrease of temperature with depth, that specimens of cold water species are mixed with the general assemblage of foraminifera on tropical ocean beds, and, as one would expect, tropical forms are totally absent in arctic and antarctic waters (see Table II, p. 60). From Schott's (1935) distribution maps of the various species of pelagic foraminifera, it is clear that ecological factors other than currents are involved in their distribution. It is probable that these are light, depth, salinity, the concentration of nutrients and the distribution of phyto- and zöo-planktonic foods (Parker, F. L., 1948, pp. 228–37). The preliminary test here described was therefore made to determine whether there is any possibility of arriving at more general conclusions concerning past oceanic temperatures from the percentage occurence not of individual species of planktonic foraminifera but of the sum of those most typical of various oceanic temperature zones. The results indicate an overwhelming influence of temperature upon their distribution (see also Glaessner, M. F., 1935, p. 190), as shown by Table III and the curves in Fig. 2. Certain anomalies are also obvious ; sample 2 shows a predominance of cold over temperate forms, while in sample 8 there is a predominance of temperate over cold although the water is considerably warmer at the first locality than at the second. From the positions of these two samples (number 2 is farther from the equator than is number 8) there is a much closer relationship with latitude than with temperature, which suggests the possibility that the distribution of the northern and southern cold species *Globigerina pachyderma* and *G. dutertrei* are at least partially governed by the low illumination in these latitudes, a fact which may explain this anomaly, where sample No. 2 is of warm origin and sample No. 8 of cold. The opposite might be true of *Globigerina bulloides* and *G. inflata* which require, perhaps, more light. Reactions to illumination in the life-cycle of foraminifera are described by E. H. Myers (1943) in a study of the widely distributed benthonic species *Elphidium crispum.* He points out that at certain periods in the cycle individuals actually appear to prefer darkness to light, but *E. crispum* is far removed taxonomically from the Globigerinidae which may behave in a very different manner. Very little is yet known about the life-cycle of planktonic foraminifera owing to the obvious technical difficulties involved in their study.

(c) Further Physical and Ecological Considerations

To a small extent, the empty tests of foraminifera would have been carried away from the original point where they first began to sink. Solution as described in section 6 may have largely removed some species, which may have once been equally abundant when alive, whilst others may on account of their thick shells have largely escaped solution. There were, however, no definite signs of apparent corrosion of the tests in the samples examined in the above described work. Bottom currents too may have caused erosion or admixture of derived and recent specimens. Slumping on steep slopes would inevitably make chaos in continuous and regular sediments, so cores should be obtained from localities where, as already mentioned (p. 45), the ocean floor is flat.

The importance of ocean currents in the distribution of planktonic animals is emphasised by Sewell (1948, p. 317–21) in his detailed study of the Copepoda of the John Murray Expedition 1933–4. To what extent ocean currents control the accumulated shell remains of foraminifera on the ocean floor is as yet unknown and cannot be known until the distribution of the individual species has been thoroughly worked out. A mixing of two currents of different origin causes mortality on a large scale due probably to the resultant temperature and food changes, which is reflected in the remains of the foraminifera on the sea-floor by an accumulation both of immature as well as adult specimens. This is apparent from the vast numbers of comminuted shells found in sample No. 7 (*Discovery* Station 83), which is at the convergence of the Benguela and West Wind Drift currents. Unlike other organisms a large accumulation of the remains of mostly adult shells would indicate an environment most suitable for their development, because, in the process of reproduction in the foraminifera, the adult parent shell is completely evacuated of protoplasm which is divided up among the offspring. The authors consider that investigations into the ecology of planktonic organisms are most important for correct geological interpretation of deep-sea cores. It would then be possible to give more exact indications of the temperature oscillations of the ocean's surface during the Pleistocene, which in its turn would be closely related to air temperatures.

The task is large and would involve : (a) the correct taxonomic identity and limits of variation allowed in the species studied, and universal agreement on the subject by all workers on cores, (b) the establishment of the distribution of each species in all oceans, (c) the comparison of these results with ocean currents and temperature limits (see Hutchins, L. W. and Scharff, M., 1947), (d) the application of the mean monthly air temperature limits and, inevitably, wind flow, to oceanographical conditions.

When data on these lines have been sufficiently accurately established, it would be possible to give a more exact interpretation of the oscillations in the frequencies of planktonic foraminifera observed in ocean core samples, but such a study would take many years. At present results from core examination must be regarded merely as important preliminary steps to more exact future work, and, with this in view, it is again stressed that radioactive determinations should be carried out on each core for the age of its fauna.

10. NOTES ON THE FORAMINIFERA USED AS TEMPERATURE-INDICATORS

A selection of the more abundant species was made in the investigation described on page 58, but a further and more detailed study of the distribution of planktonic foraminifera living in the open ocean today may prove that other species might be useful in core examination. As an example, the small cool water form *Globigerinoides elevata* (d'Orb.), which has been regarded by many writers, probably wrongly, as a variety of *Globigerinoides rubra* (d'Orb.) has only been found in very small numbers in the present examination and not at all in cores so far worked out. *Globigerinella digitata* (Brady), a tropical species which was recorded by Stubbings (1939) from the John Murray Expedition cores in the Indian Ocean and by Schott (1935) in the tropical Atlantic cores, was not identified in these samples. The significance of *Globigerina conglomerata* Schwager is somewhat doubtful at the moment. It appears that specimens found in temperate waters have more globular and lower chambers than those obtained from tropical oozes. A few specimens which could be assigned to this species were seen in the samples examined, but have not been recorded owing to the uncertainty of their correct identification. Several described species showing four chambers on the ventral surface are closely related and possibly grade into *G. conglomerata*. These are *G. helicina* d'Orb.—a highly turreted form—*G. quadrilatera* Galloway and Wissler (Pleistocene)—compressed with rather small final chamber—*G. diplostoma* Reuss with inflated chambers (recorded from the Tertiary). Some records of *G. dubia* may also be included here.

Arctic and Antarctic species :—

Globigerina dutertrei d'Orb. (Plate 2. Figs. 1a-c). This species normally predominates in Antarctic waters. In sample No. 9 it is extremely abundant and, as Earland found in several *Discovery* stations (Earland, A., 1933, p. 121), intermediate forms between this species and *G. pachyderma* (Ehr.) occur ; they appear to be of little significance from the standpoint of temperature interpretation because both species are cold forms. *G. dutertrei* has not so far been separately identified in ocean cores.

Globigerina pachyderma (Ehr.) (Plate 2, Figs. 2a–c) is the predominating cold species in Arctic waters, where *G. dutertrei* takes second place. Brady (1884, p. 600) says that the species has not been found in a pelagic state but Murray (1897, pp. 20, 21) lists it among his 26 pelagic species.

Temperate species :—

Globigerina bulloides d'Orb. (Plate 2, Figs. 3a–c). More confusion in identification has arisen with this species than with any other in the family Globigerinidae. This has been caused by allotting to it the juvenile shells of other species which are so often isomorphous, or almost so, in their early stages. Many small specimens of *Globigerinoides* can, however, be distinguished from *G. bulloides* by the presence of supplementary apertures which can quite easily be detected so long as they are matrix-free. It is therefore wise to omit very small specimens from counts because the genus *Globigerinoides* is essentially a warm temperature-indicator. To count the occurrence of its juvenile forms under *Globigerina bulloides* would give a quite erroneous impression concerning temperature.

G. bulloides is widespread in temperate regions, where it is most abundant. Phleger (1945, p. 379) points out that it is found in abundance, with *G. inflata* only, in the colder surface waters of the equatorial Atlantic and in the colder water at considerable depth. In an earlier work (1942, p. 1087) he mentions that this species may be adapted to rather colder conditions than other species of the Globigerinidae, but it is evident that *G. dutertrei* and *G. pachyderma* are the " coldest " forms (see Table II, p. 60).

In counting specimens of this species, *G. bulloides* var. *triloba* Reuss has been included.

Globigerina inflata d'Orb. (Plate 2, Figs. 5a–c). This and *G. bulloides* are the most abundant temperate forms but it appears that *G. bulloides* is somewhat more tolerant to cold temperate conditions than is *G. inflata*. The latter is easily recognisable by the rather smooth appearance of the test and the large aperture.

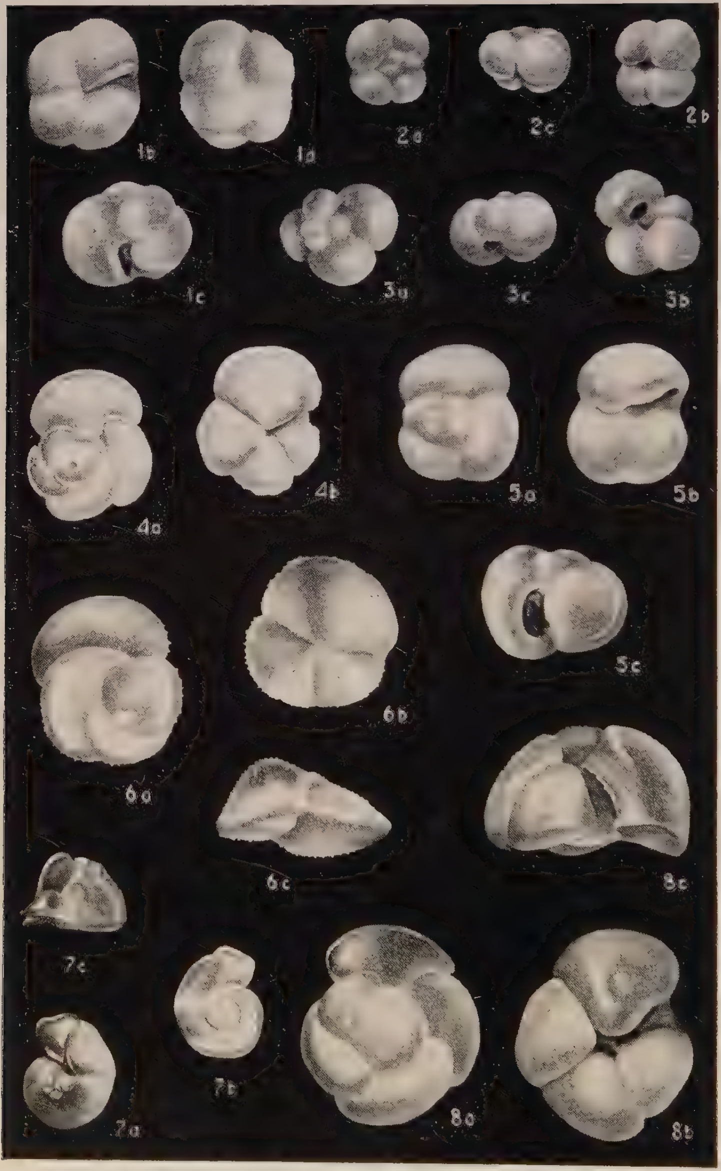
Globorotalia crassula Cushman and R. E. Stewart (Plate 2, Figs. 8a–c). There has been considerable confusion over the taxonomy of the species *Globorotalia crassa* (d'Orb.) which was originally described as *Rotalina crassa* from the Chalk of Meudon (d'Orbigny, A. D., 1840, p. 32, Plate 3, Figs. 7–8). The original is undoubtedly a *Gyroidina*. Brady described the same species under the name *Pulvinulina crassa* (d'Orb.) and figured specimens (Brady, H. B., 1884, p. 694, Plate 103, Figs. 11a–c, 12a–c) under this name. Cushman and R. E. Stewart renamed Brady's specimens *Globorotalia crassula* (Cushman, J. A., Stewart, R. E. and Stewart, K. C., 1930, p. 77, Plate vii, Fig. 1), rightly realising that they were not the same as d'Orbigny's Upper Cretaceous species, but Chapman and Parr (1937, p. 115, 116) stepped into the forum declaring a difference between Brady's two figures (11, 12). They renamed the specimens, represented by Fig. 12, *G. pseudocrassa*, but it is here considered that Chapman and Parr were incorrect.[1] Unfortunately the specimens representing Brady's Fig. 12 are missing in the *Challenger* collection but there does not appear to be sufficient difference, judging from the figures, to separate the two from the same species, and it is assumed that the species *G. crassa* recorded by workers on ocean cores are really *G. crassula*. Chapman and Parr's Figs. (1937, Plate 9, Figs. 25a–b) are less like Brady's Fig. 12 than is the latter's Fig. 11.

Globorotalia canariensis (d'Orb) (Plate 2, Figs. 4a, b) seems from the distribution so far known to be rather more typical of the warmer temperate waters than of the colder. It is quite distinct from *G. hirsuta* by the main feature of a sharp peripheral flange, whereas the latter is relatively rounded.

Globorotalia truncatulinoides (d'Orb.) (Plate 2, Figs. 7a–c).

---

[1] Since this paper went to press, specimens of *Globorotalia pseudocrassa* identified by the late W. J. Parr and kindly put aside by him for our investigation, have arrived from Australia. These have been compared with Brady's specimen of *G. crassa* and no specific differences can be detected.



RECENT COLD AND TEMPERATE WATER PLANKTONIC FORAMINIFERA

[*To face p.* 67.

This is also more abundant in the warmer temperate seas. It is very distinctive with its tall ventral and flat dorsal surfaces, and cannot be confused with any of the other *Globorotalinae*. It has been recorded as *Pulvinulina truncatulinoides* from the Miocene of Australia by Heron-Allen and Earland (1924, p. 180), a single specimen of which is preserved in the British Museum (Natural History) collections.

Globorotalia hirsuta (d'Orb.) (Plate 2, Figs. 6a–c). As its name implies the surface is covered with small sturdy spines. Although somewhat similar to *G. canariensis* it can usually be distinguished by the presence of spines and by its rounded peripheral margin. Normally four chambers are visible on the ventral surface but occasionally only three, as shown in Plate 2, Fig. 6b. Its geological range is Pliocene to Recent, and it is found in abundance in the Matanzas formation of the Cuban Pliocene (Cushman, J. A. and Bermudez, P. J., 1949, p. 36). It is today abundant in the Atlantic from Carolina to the British Isles (*op. cit.*).

Warm and Tropical forms :—

Orbulina universa d'Orb. (Plate 3, Fig. 6). Little need be said about this easily recognisable form. Cretaceous records of it are now discredited (see Earland, A., 1939, p. 30 *et seq.*). The first genuine record of it appears to be that of Le Roy (1948) in the Miocene of the East Indies. Le Roy proposes an "*Orbulina* surface" datum line in establishing world-wide Tertiary time-stratigraphical correlation, because it appears abruptly over the whole East Indian area. In the same paper he argues that in general in the Tertiary "pelagic foraminifera hold the solution for improving and establishing more accurate long range correlation," because benthonic forms are so much more dependent in their distribution on other ecological factors reflected in local facies, whereas pelagic foraminifera are exclusively effected by the condition of the surface layers of the sea. *Orbulina universa* might indeed prove to be useful as a pelagic time-marker provided it spread over the oceans in vast numbers and at great speed, but nothing is known of the rate of propagation of the species over the ocean surface waters.

Globigerina dubia Egger (Plate 3, Figs. 10a, b). In recording the occurrence of this species, specimens ranging from low turreted to high turreted forms covering several described species have been used. Although further work on this matter is necessary from a large number of specimens, it seems likely that there is a continuous morphological gradation from forms such as *G. subcretacea* Lomnicki, 1901 [=*G. subcretacea* Chapman, 1902 and *G. cretacea* d'Orb.?, Brady (1884, Plate 82, Fig. 10) *non G. cretacea* d'Orb.] to the high turreted form *G. eggeri* Rhumbler, 1901. Difficulty was encountered in separating specimens when examining the samples and it was decided to include them under the simple heading *G. dubia* Egger, the name which bears nomenclatural priority. Almost certainly it includes the form used by Phleger (1948) under *G. eggeri*, but Phleger makes no mention of the amount of latitude he gave this apparent variation of form. A parallel type of variation is evident in *Globigerinoides rubra* (d'Orb.) (see below).

By working on these lines, the use of this species as a temperature-indicator in these nine samples has not been impaired because the species and its variants appear to be "warm," although its occurrence accounts for 74 specimens out of 98 tropical forms in sample No. 3 (Table II, p. 60). Its survival across the Atlantic on the Gulf Stream Drift is thus suggested. According to Phleger (1939, p. 1404) the species (here called *G. dubia*) is most common along the path of the Gulf Stream off the continental slope of America and less so on the slope. It may be a very hardy form which has survived passage across the Atlantic to south-west Ireland on the Gulf Stream Drift.

Globigerinella aequilateralis (Brady) (Plate 3, Figs. 9a, b). A tropical species which shows variation from an almost open coil (Brady, 1884, Plate 80, Figs. 18, 19) to a stout involute form which Cushman (1917, p. 662 ; figd. in Cushman 1921, p. 293, Fig. 11) named *G. aequilateralis* var. *involuta* such as is figured here (Plate 3, Fig. 9a, b). The species and variety have been counted together because the two indicate an entirely continuous morphological series in the amount of coiling.

Globigerinoides rubra (d'Orb.) (Plate 3, 12a, b). Stubbings (1939, p. 171) points out that the remains of this species survive best in shallow water, due in part, he suggests, to solution of the thin walled test—an important factor in temperature distribution records (see p. 48). Considerable variation in the height of the spire is shown. The amount of red pigment is also variable and it may be that specimens living at greater depths are incapable of producing pigment to the extent achieved by those living near the surface, owing to the differences in amount of light penetration.

Globigerinoides sacculifera (Brady) (Plate 3, Fig. 5). This is an easily recognisable form with long, tapering later chambers. It seems to occur everywhere in tropical oceanic deposits. Its close ally, *G. digitata* (Brady), was not definitely identified in the counting of these samples but some of the small specimens allotted to *G. sacculifera* may have belonged to this species. *G. digitata* is mainly confined to the Indo-Pacific tropical seas.

Globigerinoides conglobata (Brady) (Plate 3, Figs. 8a, b). An easily recognisable though not very common species which, judging from the figures, is closely related to Galloway and Wissler's Pleistocene species *Globigerina* (=*Globigerinoides*) *cyclostoma* (1927, p. 42, Plate 7, Figs. 8, 9) from California.

Globorotalia menardii (d'Orb.) (Plate 3, Figs. 1a–c). This unfailing indicator of tropical surface waters is occasionally crenulated on the peripheral flange and was separated as a variety, var. *fimbriata* by Brady (1884, p. 691, Plate 103, Fig. 3). The specimen figured here (Plate 3, Fig. 3) is less crenulated than Brady's specimen but those of the variety in samples examined merge with the species and are therefore included with it in the counts.

Globorotalia tumida (Brady) (Plate 3, Figs. 2a–c) is distinct from the previous species but closely allied to it (see Cosijn, A. J., 1942, p. 39 *et seq.*). It is less abundant than *G. menardii* but is apparently of similar distribution.

Globorotalia scitula (Brady) (Plate 3, Figs. 11a–c). Although not common in these samples, it has been recorded because other authors have used it in core determinations. The species seems to overlap from tropical to warm temperate waters but with the small amount of material investigated here, it is unsafe to attribute it mainly to tropical or temperate occurrence. The species may range from the Miocene because the earliest record of its occurrence appears to be that from the Kythrean of Cyprus (Ovey, C. D., 1937, p. 111, Table 1), a formation now ascribed to the Lower Miocene (Henson, F. R. S., Browne, R. V. and McGinty, J., 1949, pp. 22–24).

Sphaeroidinella dehiscens (d'Orb.) (Plate 3, Fig. 4). Although this species is known to have a wide distribution in warm waters t is nowhere abundant in these samples. Stubbings (1939, p. 174) notes that it tends to be more frequent in samples from deeper water, due, he suggests, to the survival of their massive tests compared with those of more delicate species (see p. 48).

Pulleniatina obliquiloculata (Parker and Jones) (Plate 3, Fig. 7). Known as an excellent indicator of warm water, this species appears o be of local abundance within the warm water limits of the Atlantic, and suggests some other ecological factor controlling such a distribution (see p. 62).

11. IMPLICATIONS OF CLIMATIC CHANGES FROM THE STUDY OF THE DEEP-SEA FLOOR

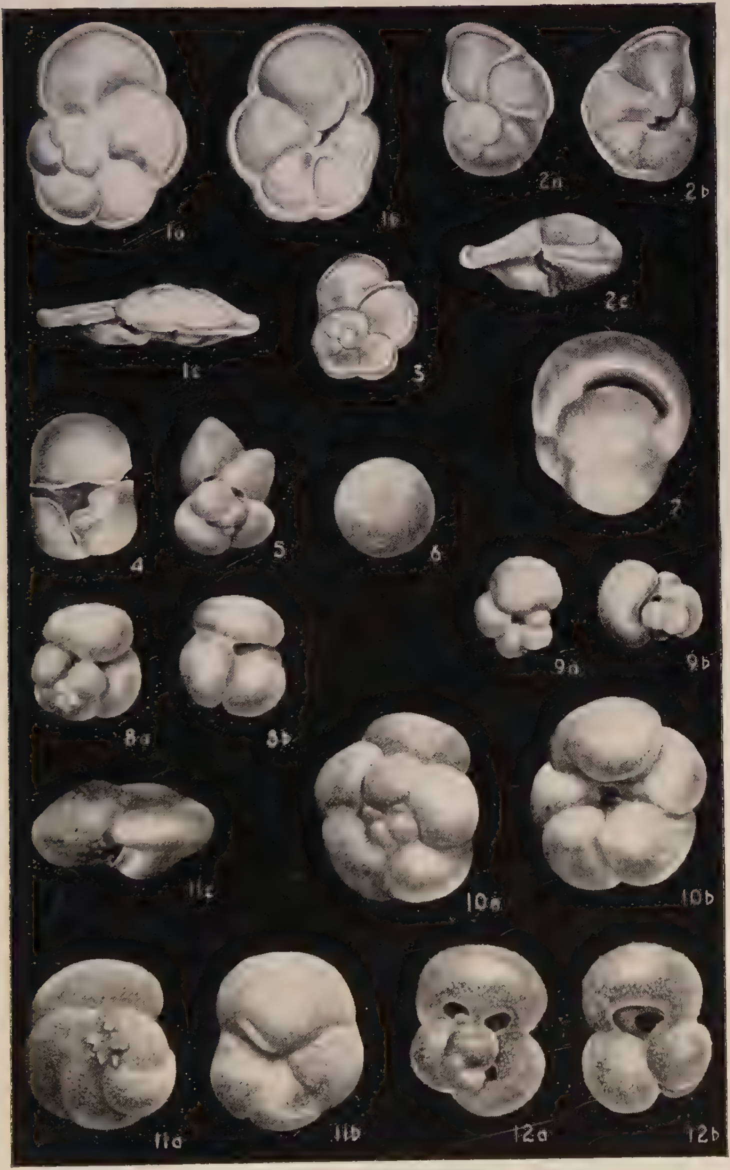
At present it is possible that only the Pleistocene and perhaps part of the Pliocene can be represented by ocean bottom cores, but here seems little doubt that oceanic sediments are likely to give a more complete record of geological history than any succession on and or from the deposits laid down on the continental shelf.

Most of the current and obsolete theories, both valid and invalid, of the origin of climatic oscillations are listed by C. E. P. Brooks (1949), but those most likely to be effective are discussed n chapters IV, V and XII (*ibid*, pp. 89–109, 201–20). It is evident hat, when sufficient cores have been studied from various parts of he oceans, correlations so obtained between them will throw important light upon the dating and the synchronisation or alternation of Pleistocene climatic fluctuations in the two hemispheres. These studies, using the Urry radioactive technique of dating (p. 54) may prove or disprove the adaptation of the Milankovitch curves based on the rhythmic change in the earth's ecliptic, variability in the earth's orbit and the precession of the equinoxes (Zeuner, F. E., 1945, Chaps. V and VI, p. 136–75). This hypothesis would suggest a north and south oscillation of the thermal equator and at least a partial alternation in glacial and interglacial periods in the two polar and temperate regions, although such an alternation might to a considerable extent be masked by continentality. On the other hand, glacial advances and retreats may prove to be synchronous in the two hemispheres, which would lend support to theories of increased or decreased solar radiation. The probable contemporaneity of climatic fluctuations in the two hemispheres is strongly supported by Nilsson (1949, p. 204) who stresses the parallel position of the present snow-line and that of the maximum phase of the Würm (Wisconsin) along the whole length of the Cordillera from the Rockies to the southern Andes (Klute, F., 1928).

It is, perhaps, not out of place to clarify the confusion caused by referring, as many do, to Zeuner's hypothesis as the " Radiation Theory." This gives the impression that in effect a change in solar output accounts for the Milankovitch time-curve, when it is merely a question of the amount of received radiation dependent on the position of the earth in relation to the sun. The term " Radiation Theory " should only be applied to those theories which attempt explanations of climatic oscillations based on changes in solar radiational output.

When attempting interpretations of faunal indications, conclusions from single cores are likely to be further complicated by minor oscillations in restricted localities and local changes in oceanic circulation.

The various current theories concerning the origin of climatic fluctuations during the Pleistocene have been usefully discussed by Willett (1949, 1949a). He supports the view that variability of solar radiation (i.e., in the solar constant) is mainly responsible for fluctuations, reasoning from observed recent minor changes and their relation to sunspot activity. Brooks (1949a, p. 173) points out that the variation of solar activity associated with sunspots is a different effect from that of changes in the solar constant, which has little if any direct relation to the sunspot number. Willett compares these short-term changes, which affect both hemispheres simultaneously, with week to week and month to month fluctuations in relation to the general circulation pattern of the atmosphere based essentially on the current theory of a contraction or expansion of the circumpolar zonal vortex. By piecing together analogies of this kind he concludes that stress should be laid on Simpson's solar radiation theory—involving an increase in radiation to produce



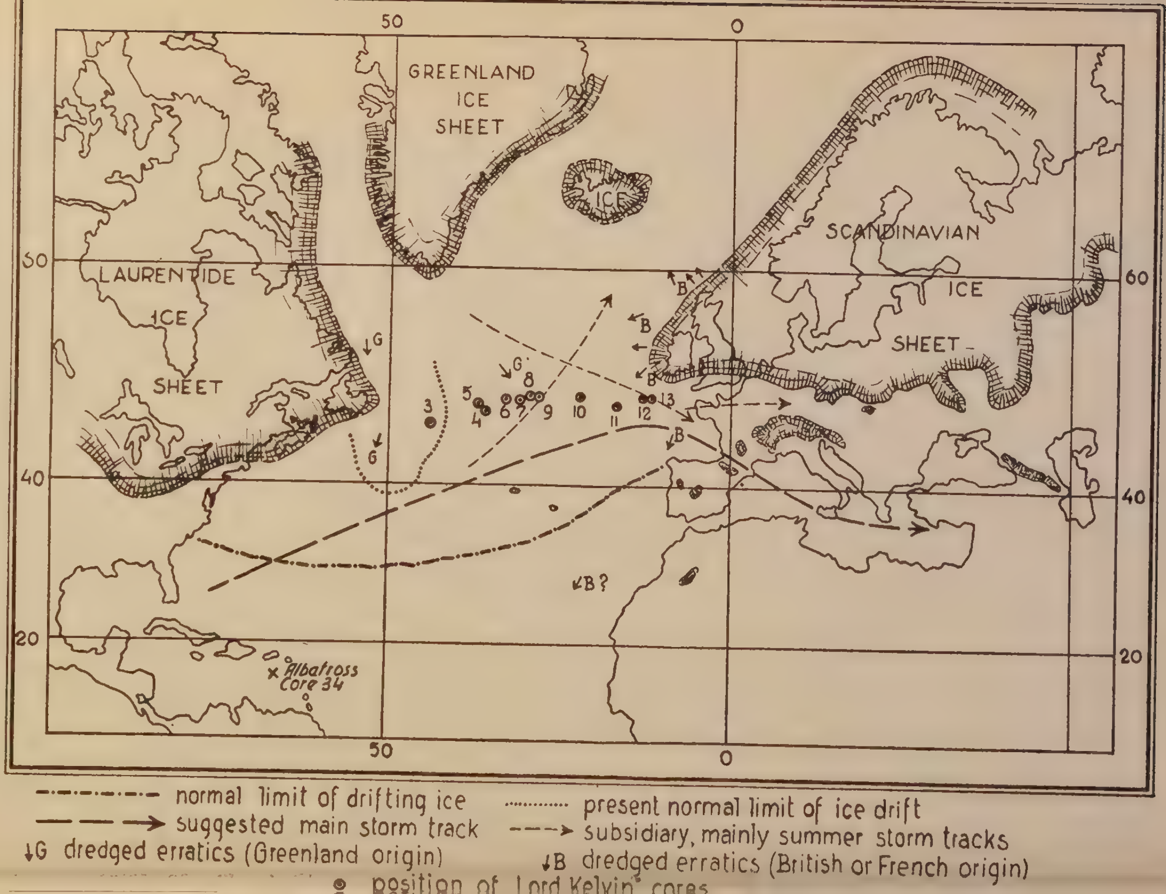
RECENT WARM WATER PLANKTONIC FORAMINIFERA

[*To face p.* 70

a cold fluctuation—for the origin of fluctuations during the Pleistocene (Brooks, C. E. P., 1949, Chap. IV, p. 89 *et seq*.). Willett (1949, p. 46) also draws attention to the implication that it seems almost certain that continentality is a primary requirement for the initiation of an ice age since cold periods follow orography (see Brooks, *op. cit*., Chap. X, p. 177 *et seq*). Flint (1947) favours a decrease in solar radiation to correspond with a cold period, combined with continentality. He elaborates upon these ideas giving them the name Solar-topographical Hypothesis. He says that the two essential elements in the hypothesis are, first, fluctuations in the solar radiation curve as the cause of world-wide temperature changes, and, secondly, the presence of highlands as the prime factor responsible for the accumulation of snow and the distribution of glaciers. He may thus account for the considerable lag which occurs between the Alpine orogenesis and the first glaciation of the Pleistocene : the orogenesis had started in Eocene times and virtually ended in early Pliocene, long before the first ice sheet appeared. Not until the Pleistocene were both of Flint's requisites operating favourably for an ice age. Fuchs and Paterson (1947) adopt continentality but substitute variabilities in the solar constant by the effect of vulcanicity on the absorption of solar radiation. With a wealth of information from volcanic deposits and their relation to the variation in the levels of Lake Rudolf, East Africa and to pluvial periods, their work lends much support to the theory that these periods in the tropics were contemporaneous with cold periods in temperate zones and accompanied by uplift of the continents to initiate glaciation. In other words, during the Pleistocene, orogeny and continental uplift appear to have been the primary causes, while vulcanicity was possibly the trigger which provided the necessary cooling effect in the atmosphere by absorbing solar radiation. Their hypothesis thus substitutes a terrestrial for an extra-terrestrial explanation for the main changes in the solar radiation received by the earth. It does not, however, entirely neglect Simpson's stress on the importance of variability of the solar constant, and would, with the theory of Paschinger (who claims that the development of ice sheets causes changes in their supply of moisture—see Brooks, C. E. P., 1949, Chap. 16, p. 271) account for " the bifid character of glacial advance in high latitudes " (Fuchs, V. E. and Paterson, T. T., 1947, pp. 330, 331, text-Fig. 5). More recently Nilsson (1949) gives added support to the correspondence of pluvial periods in East Africa with the glacial advances of the Pleistocene with a table (*ibid*. p. 210, Fig. 4) of the correlation of the main phases of the Pleistocene in the Himalayas, East Africa, Egypt and Palestine, the Alps, North Europe and North America.

It is worth recalling what has recently been said by Hoyle (1949, p. 161) who represented the Royal Astronomical Society at a discussion with the Royal Meteorological Society on post-glacial climatic change. He considered that it was " putting the cart before the horse " to attempt to explain all possible climatic variations by purely terrestrial means before exploring the possible variations of the solar constant. Only very small changes in it are required to produce observed climatic changes. In their paper Hoyle and Lyttleton (1939) give valuable data concerning clouds of interstellar matter on the sun's radiation. It is shown that the sun passing periodically through these nebulous clouds will capture sufficient material to bring about considerable changes in the quantity of radiation emitted. The quantity of gathered matter depends directly on the density of the cloud and inversely on the cube of the sun's velocity relative to the cloud. Changes up to 10 per cent in the constant of the whole spectrum (first suggested by Simpson) are adequate to produce substantial climatic variations over the whole earth. Suppose, however, that the increment of the constant consisted almost entirely of ultra-violet radiation, the solar constant would only have to be changed by 1 per cent to make appreciable changes in the terrestrial climate. The reason for this lies in the photo-chemistry of the atmosphere, which is largely opaque to infra-red—a property largely arising from CO_2 molecules. Moreover, it has been proved by observation that excess emission does in fact occur in the ultra-violet part of the spectrum. The variation in the amount of CO_2 in the atmosphere has been thought to have only a very limited effect on climatic fluctuations (Brooks, C. E. P., 1949, pp. 116, 265). The interesting analogy, however, of the present increase in world temperatures and in the output of CO_2 from the burning of coal and oil, is given by Callendar (1949, pp. 310–14) in a recent article. World climates according to him are behaving in such a manner as to suggest that slightly more heat is steadily being retained in the atmosphere which could be due to an increasing opacity to terrestrial heat because of additional CO_2 Nevertheless he has taken the precaution to point out that the present oscillations, if any, in the sun's constant are not known, so the matter cannot be proved. As regards changes in the earth's orbit Hoyle (1949, p. 162) claims that these could only produce small periodic fluctuations and could in no way be responsible for major changes, a view which is supported by Simpson (1940, p. 216).

It is obvious from the above summarised outline of recent ideas on the climatic fluctuations of the Pleistocene that it would be premature, with only a few cores so far studied, to suggest any comparison between the results obtained from an analysis of the foraminiferal content and any particular theory advanced to explain climatic fluctuations. Pettersson (1949, p. 4) tentatively suggests, however, that results from the study of cores taken in the eastern Atlantic, which have not yet been published, indicate fluctuations which tally with the Milankovitch-Zeuner time-curve. It would seem to the authors that, before any definite conclusions can be


50
0
GREENLAND ICE SHEET
ICE
SCANDINAVIAN ICE SHEET
LAURENTIDE ICE SHEET
50
60
40
40
20
20
50
0
G
G
G
B
B
B
B
B
B?
3
4
5
6
7
8
9
10
11
12
13
Albatross Core 34
normal limit of drifting ice
suggested main storm track
G dredged erratics (Greenland origin)
present normal limit of ice drift
subsidiary, mainly summer storm tracks
B dredged erratics (British or French origin)
position of Lord Kelvin' cores

made, it is necessary to correlate a large number of cores taken in a north–south direction in both hemispheres. They would reveal (a) whether cold fluctuations alternated between hemispheres or not, (b) whether and, if so, by how much, the tropics cooled when the continents of the temperate regions were ice-capped or remained unchanged, (c) whether the tropical belt migrated and (d) whether, possibly, volcanic activity correlated with world climatic cooling. Not until such points as these have been settled are students of the subject in sufficiently strong a position to accept or refute the various theories, or combinations of them, which depend so much on ocean core study for proof of their validity (see Deacon, G. E. R., 1949 and Ovey, C. D., 1949).

Provided that there is a connection between the southerly drift of icebergs and the southward flow of winds of polar origin, support would be given by the distribution of dredged erratics in the Atlantic Ocean to the theory of the southward displacement during the Pleistocene of the polar front—the boundary between polar and tropical air masses along which Atlantic depressions develop (Flett, J. S., 1904, and Peach, B. N., 1912). Further support is given by the southern limits of glacial marine deposits (Bramlette, M. N. and Bradley, W. H., 1942, p. 8, Fig. 2). It is however interesting to note that the southern limit of erratics approximates to the line of abnormal occurrence of icebergs during the period 1900–16 (Jenkins, J. T., 1921, p. 89, Fig. 14). Some of those recorded by Flett and Peach probably represent the larger ice-borne material, derived from the topmost glacial marine bed. Many of these were evidently only partly buried in globigerina ooze and had probably been dropped by recent icebergs (Peach, B. N., 1912, p. 272). The dredging off the north-west coast of Africa (Fig. 3) contained among other things (*op. cit.* p. 278) chalk flints, but the possibility that they were contributed by ships' ballast must not be ignored.

The centres of depressions would probably have moved during the major glaciations along the track indicated in Fig. 3, and would become mainly diverted into the Mediterranean. The British Isles would normally be situated on the edge of the high pressure system over the ice sheet (see Brian, K. and Cady, R. C., 1942, and Zeuner, F. E., 1937 and 1945). A similar type of meteorological régime on a small time-scale was experienced during the cold period of 23rd January to 16th March, 1947, when over the British Isles the mean pressure was lowest to the south-west and highest to the north-east, and many (but not all) low pressure systems either passed into the Mediterranean or were held back in the Atlantic by high pressure over snow-covered Europe.

12. CONCLUSIONS AND ACKNOWLEDGMENTS

The deep-sea floor is becoming increasingly important for the study of the earth's major tectonic features. With the development of echo sounding there is accumulating a wealth of bathymetrical information, and as a result it is now possible to give a rational classification of deep-sea features, as well as to discuss in favourable cases their age and mode of formation. It is concluded, largely on a basis of morphology, that the major ridges of the ocean are, for the most part, compressional features, but it is desirable that this theory should be tested by a detailed survey on one or more of the ridges. For such a survey it is essential that the echo profiles should form a close network, and that modern methods should be used for accurate position finding. It would be of the greatest significance if more specimens of solid rocks could be obtained from the major oceanic ridges, as definite evidence would be then obtained about their nature, and, in favourable circumstances, evidence about their date of formation. Finally, core samples should be obtained on both sides of the ridge, and there should be a close collaboration with geophysical work. There is little evidence concerning the origin and date of formation of deep-sea basins, but the immense thickness of sediments found in the East Atlantic Basin suggests that they are at least in part of considerable antiquity. It would seem to the authors that the value of geophysical work is considerably reduced if it is not done in conjunction with morphological, geological, mineralogical and physical and chemical oceanographical investigations.

As morphology of the deep-sea floor influences the character of sediments in three essentially different ways (first through slumping, secondly through its influence on texture and thirdly through its chemical and environmental influence), a knowledge of the subject is important for a genetical study of deep-sea sediments.

The deep-sea floor has in places an unrivalled record of geological and climatological changes, and detailed investigations of long cores collected in favourable localities should give much valuable information about these events. Significant periods in oceanic history may be revealed through sedimentary (chemical, textural and mineralogical) or biological changes. As many of the causes affecting chemical composition are to some extent interdependent, there is at present considerable uncertainty about the reason for any chemical change. It is possible that the difficulty may be overcome if future investigations show that there is some unique property of the non-biological component which remains reasonably constant in any sedimentary type. It is suggested that titanium may be a suitable element in the case of globigerina ooze and red clay, especially because titanium in sea-water has only been detected spectrographically.

From a study of planktonic foraminifera in bottom samples collected in a roughly north–south direction from the Atlantic Ocean it has been possible to show that they are useful indicators of the sea-surface temperature. It is, however, not yet possible to assign exact temperature limits to the ocean surface from the percentage distribution of the various species, but it may be possible to do so when the distribution of the species is more fully known. It is at present possible, by means of a detailed foraminiferal analysis, to give indications of the ocean surface temperature throughout the geological time represented by a long core.

Statistical foraminiferal investigations, and possibly similar studies on diatoms and other marine organisms sensative to temperature change, combined with sedimentary investigations (chemical, mineralogical, textural, including the recognition of glacial marine deposits) on a large number of cores collected from both hemispheres will, in the opinion of the authors, give the fullest record of past climatic changes. Even the pollen-grain content in certain instances would assist and might be of particular importance in the determination of past prevailing wind directions from land to sea (see Wiseman, J. D. H., 1949, p. 682). It will of course be necessary to relate these changes to a time scale, and in consequence the work should be carried out in conjunction with radioactive determinations, which, by means of the Urry technique, give time-depth relations for the latter half of the Pleistocene.

The authors are particularly grateful to Dr. F. M. Kicinski for the care, time and trouble which he has taken in the preparation of the text-figures and tables, and especially for his excellent camera lucida reproductions of foraminifera. Their thanks are also due to the Hydrographer of the Royal Navy and to the Director of the Meteorological Office, Air Ministry, for information concerning temperature and oceanographical conditions, and to the members of their staffs, who have taken much trouble in making the data available. They are also grateful to Dr. W. Campbell Smith, C.B.E., of the British Museum (Natural History) for his criticism and for reading the manuscript.

13. REFERENCES

AMORETTI, C. 1801. Premier voyage autour du Monde par le chevr. *Pigafetta.* Paris, l'an. 9.

ARCHANGUELSKY, A. D. 1930. Slides of sediments on the Black Sea bottom in the importance of this phenomenon for geology. *Bull. Soc. Nat. Moscou* (Geol.) 38, pp. 31–80.

ARRHENIUS, G. 1948. The concentration of nitrogen in samples of cores 13, 15 and 16. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 5, No. 13, pp. 30–3.

———. 1948a. The phosphate content of some sediments from the Mediterranean. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 5, No. 13, pp. 26–9.

BOUCART, J. 1949. *Géographie du fond des mers.* Paris.

BRADY, H. B. 1884. Report on the scientific results of the voyage of H.M.S. *Challenger*. Report on the foraminifera (2 vols. text and Plates), Zool. 9.

BRAMLETTE, M. N. and BRADLEY, W. H. 1942. Geology and biology of North Atlantic deep-sea cores between Newfoundland and Ireland. Part I. Lithology and geologic interpretation. *U.S. Geol. Surv. Prof. Paper* 196-A, pp. 1–34.

BROOKS, C. E. P. 1949. *Climate through the ages.* (Revised ed.), London.

———. 1949a. Causes of climatic fluctuations (in discussion on post-glacial climatic change). *Quart. J. Roy. Met. Soc.*, 75, pp. 172–4.

BROWNE, B. C. and COOPER, R. I. B. 1950. British submarine gravity survey of 1938 and 1946. *Phil. Trans. Roy. Soc. Lond.* (A), 242, pp. 243–310.

BRYAN, G. S. 1940. A bathymetric chart of the North Pacific Ocean. *Ass. Océanog. Union Géod. Géophys. Internat.*, Publ. Sci. No. 8, pp. 78–80.

BRYAN, K. and CADY, R. C. 1942. The Pleistocene climate of Bermuda. *Amer. J. Sci.*, (5), 27, pp. 241–64.

BULLARD, E. C. and GASKELL, T. F. 1941. Submarine seismic investigations. *Proc. Roy. Soc.* London (A), 177, pp. 476–97.

CALLENDAR, G. S. 1949. Can carbon dioxide influence climate ? *Weather*, London, 4, pp. 310–14.

CHAPMAN, F. and PARR, W. J. 1937. Foraminifera. *Sci. Rep. Aust. Antarctic Exped. 1911–14.* (C. Zool. Bot.) 1, 2. 190 pp., pls. 7–10.

COOPER, L. H. N. 1948. The distribution of iron in the waters of the western English Channel. *J. Mar. Biol. Ass. U.K.*, 27, pp. 279–321.

CORRENS, C. W. 1930. Über einen Basalt vom Boden des Atlantischen Ozeans und seine Zersetzungsrinde. *Chem. d. Erde*, Jena, 5, pp. 76–86.

———. 1935. Die Sedimente des Äquatorialen Atlantischen Ozeans. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess. " Meteor,"* 1925–1927, B.3, Tl.3, Lief. 1, pp. 1–42.

———. 1937. Des Sedimente des Äquatorialen Atlantischen Ozeans. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess. " Meteor,"* 1925–1927, B.3, Tl.3, Lief. 2, pp. 191–262.

COSIJN, A. J. 1942. Statistical studies on the phylogeny of some foraminifera. Cycloclypeus and Lepidocyclina from Spain, Globorotalia from the East-Indies. *Leid. geol. Meded.*, 10, pp. 1–170.

CREAK, E. W. 1904. Report on the results of the magnetic survey of Funafuti Atoll by the officers of H.M.S. *Penguin.* The Atoll of Funafuti. *Rep. Coral Reef Comm. Roy. Soc. Lond.*, pp. 1–420.

CUSHMAN, J. A. 1917. New species and varieties of foraminifera from the Philippines and adjacent seas. *Proc. U.S. Nat. Mus.* 51, pp. 651–62.

———. 1921. Contributions to the biology of the Philippine Archipelago and adjacent regions. Foraminifera of the Philippine and adjacent seas. *Bull. U.S. Nat. Mus.*, 100, 4608 pp., 100 pls.

——— and BERMUDEZ, P. J. 1949. Some Cuban species of *Globorotalia. Contr. Cushman Lab.*, 25, pp. 26–45.

——— and HENBEST, L. G. 1942. Geology and biology of North Atlantic deep-sea cores. Part 2. Foraminifera between Newfoundland and Ireland. *U.S. Geol. Surv. Prof. Paper* 196-A, pp. 35–54, pls. 8–10.

———, STEWART, R. E. and STEWART, K.C. 1930. Tertiary foraminifera from Humboldt County, California. A preliminary survey of the fauna. *Trans. San Diego Soc. Nat. Hist.*, 6, pp. 41–94, pls. 1–8.

DALY, R. A. 1925. Geology of Ascension Island. *Proc. Amer. Acad. Arts Sci.*, 60, pp. 1–80.

———. 1926. *Our mobile earth.* New York.

DEACON, G. E. R. 1949. Contribution to discussion on " post-glacial climatic change." *Quart. J. Roy. Met. Soc.*, 75, p. 179.

DEFANT, A. and HELLAND-HANSEN, B. 1939. Die Altair Kuppe. *Abh. preuss. Akad. Wiss.*, 1939, 5, pp. 40–5.

DOBRIN, M. B., PERKINS, B., Jr. and SNAVELY, B. L. 1949. Subsurface constitution of Bikini Atoll as indicated by seismic refraction survey. *Bull. Geol. Soc. Amer.*, 60, pp. 807–28.

EARLAND, A. 1933. Foraminifera, Part II. South Georgia. "*Discovery*" *Rep.*, 7, pp. 27–138, pls. i–vii.

———. 1939. Chalk: its riddles and some possible solutions. *Trans. Herts. Nat. Hist. Soc. Fld. Cl.*, 21, pp. 6–37.

EINSELE, W. and VETTER, H. 1938. Untersuchungen über die Entwicklung der physikalischen und chemischen Verhältnisse im Jahreszyklus in einen mässig eutrophen See. *Int. Rev. Hydrobiol.* Leipzig, 36, pp. 285–324.

EMERY, K. O. 1949. Topography of sediments in the Arctic Basin. *J. Geol.*, 57, pp. 512–21.

——— and DIETZ, R. S. 1941. Gravity coring instrument and mechanics of sediment coring. *Bull. Geol. Soc. Amer.*, 52, pp. 1685–714.

ESENWEIN, P. 1930. Petrographische Untersuchungen an Gesteine von Paloweh. *Vulkan. en Seismol. Meded.*, 11, pp. 95–141.

EVANS, R. D. and KIP, R. F. 1938. The radium content of marine sediments from the East Indies, the Philipines and Japan, and of the Mesozoic fossil clays of the East Indies. *Amer. J. Sci.* (5), 36, pp. 321–36.

——— and MOBERG, E. G. 1938b. The radium and radon content of Pacific Ocean water, life and sediments. *Amer. J. Sci.*, 36, pp. 241–59.

EVE, A. S. 1909. On the amount of radium present in sea-water. *Phil. Mag.*, (6) 18, pp. 102–7.

EWING, M. 1948. Exploring the Mid-Atlantic Ridge. *Nat. Geogr. Mag.*, 94, pp. 276–94.

———, CRARY, A. P. and RUTHERFORD, H. M. 1937. Geophysical investigations in the emerged and submerged Atlantic coastal plain. *Bull. Geol. Soc. Amer.*, 48, pp. 753–813.

———, WOLLARD, G. P., VINE, A. C. and WORZEL, J. L. 1946. Recent results in submarine geophysics. *Bull. Geol. Soc. Amer.*, 57, pp. 909–34.

———, WORZEL, J. L., HERSEY, J. B., PRESS, F. and HAMILTON, G. R. 1949. Seismic refraction measurements in the Atlantic Ocean Basin. *Bull. Geol. Soc. Amer.*, 60, p. 1303.

FARQUHARSON, W. I. 1936. Topography. *John Murray Exped.* 1933–34, *Sci. Rep.* I, pp. 43–61.

FLEMING, R. H. and REVELLE, R. 1939. Physical processes in the ocean. *In* Trask, P. "Recent marine sediments. A symposium," pp. 48–152. London.

FLETT, J. S. 1904. Report on the rock specimens and some of the oozes collected by the S.S. *Faraday* and S.S. *Ninia* from the bed of the Atlantic Ocean in 1903. *J. Roy. Geogr. Soc.* (extra publ.) 1904, pp. 23–7.

FLINT, R. F. 1947. *Glacial geology and the Pleistocene epoch.* New York and London.

FUCHS, V. E. and PATERSON, T. T. 1947. The relation of volcanicity and orogeny to climatic change. *Geol. Mag.*, London, 84, pp. 321–33.

GALLOWAY, J. J. and WISSLER, S. G. 1927. Pleistocene foraminifera from the Lomita Quarry, Palos Verdes Hills, California. *J. Paleont.*, 1, pp. 35–86, pls. 7–12.

GLAESSNER, M. F. 1945. *Principles of micropalaeontology.* Melbourne and Oxford.

GRIM, R. E., DIETZ, R. S. and BRADLEY, W. F. 1949. Clay mineral composition of some sediments from the Pacific Ocean off the Californian Coast and the Gulf of California. *Bull. Geol. Soc. Amer.*, 60, pp. 1785–1808.

GRIPENBERG, S. 1934. A study of the sediments of the North Baltic and adjoining seas. *Fennia*, Helsingfors, 60, pp. 1–231.

———. 1937. The calcium content of Baltic water. *J. Cons. int. Explor. Mer*, 5, pp. 283–304.

GUTENBERG, B. and RICHTER, C. F. 1941. Seismicity of the earth. *Geol. Soc. Amer. Spec. Paper*, 34, 131 pp.

HALKYARD, E. 1919. *The fossil foraminifera of the Blue Marl of the Côte des Basques, Biarritz* (ed. E. Heron-Allen and A. Earland). Manchester.

HANGUCHI, H. 1938. Chemical investigations of deep-sea deposits. I. Radium constants of deep-sea deposits. *J. Chem. Soc. Japan*, 59, pp. 171–7.

HARVEY, H. W. 1945. Recent advances in the chemistry and biology of sea water. Camb.

HAUG, E. 1907. *Traité de géologie*, 1. Paris.

HEIM, A. 1908. Über rezente und fossile subaquatische Rutschungen und deren lithologische Bedeutung. *N. Jb. Min. Geol. Paläont.*, 1908, 2, pp. 136–57.

HEISKANEN, W. 1945. The gravity anomalies of the Japanese Islands and in the waters east of them. *Ann. Acad. Sci. Fenn.*, (A) 3, Geol.-Geogr., 8, pp. 1–22.

HELLAND-HANSEN, B. 1912. The ocean waters. An introduction to physical oceanography. *Int. Rev. Hydrobiol.* Leipzig, 3 (supl.), ser. 1, 142, pp. 1–88.

HENSON, F. R. S., BROWNE, R. V. and MCGINTY, J. 1949. A synopsis of the stratigraphy and geological history of Cyprus. *Quart. J. Geol. Soc. Lond.*, 105, pp. 1–41.

HERDMAN, H. F. P. 1948. Soundings taken during the *Discovery* Investigations 1932–9. "*Discovery*" *Rep.*, 25, pp. 39–106.

HERON-ALLEN, E. and EARLAND, A. 1924. The Miocene foraminifera of the "Filter Quarry," Moorabool River, Victoria, Australia. *J. Roy. Micr. Soc.*, pp. 121–86, pls. vii–xiv.

HESS, H. H. 1938. Gravity anomalies and island arc structure with particular reference to the West Indies. *Proc. Amer. Phil. Soc.*, 79, pp. 71–96.

———. 1946. Drowned ancient islands of the Pacific Basin. *Amer. J. Sci.*, 244, pp. 772–91.

———. 1948. Major structural features of the Western North Pacific, an interpretation of H.O. 5485 bathymetrical chart, Korea to New Guinea. *Bull. Geol. Soc. Amer.*, 59, pp. 417–46.

———. 1948a. Further comment on guyots and atolls in the light of recent information. *Ann. Rep. Smithson Instn.*, 1947, pp. 297–300.

HJULSTRÖM, F. 1939. Transportation of detritus by moving water. *In* Trask, P. "Recent marine sediments. A symposium." pp. 5–31. London.

HOLMES, A. 1933. The thermal history of the earth. *J. Wash. Acad. Sci.*, 23, pp. 169–95.

HOOKE, R. 1667. To sound the deepest seas without a line by the help of an instrument referred by Figure 2. *Philos. Trans.*, 2, pp. 439–43.

HOYLE, F. 1949. External sources of climatic variation (in discussion on post-glacial climatic change). *Quart. J. Roy. Met. Soc.*, 75, pp. 161–3.

——— and LYTTLETON, R. A. 1939. The effect of interstellar matter on climatic variation. *Proc. Camb. Phil. Soc.*, 35, pp. 405–15.

HUTCHINS, L. W. 1947. The bases for temperature zonation in geographical distribution. *Ecol. Monogr.*, 17, pp. 325–35.

——— and SCHARFF, M. 1947. Maximum and minimum monthly mean sea surface temperatures charted from the "World atlas of sea surface temperatures." *J. Mar. Res.*, 6, pp. 264–8, pls. 1, 2.

HVORSLEV, M. J. and STETSON, H. C. 1946. Free-fall coring tube: a new type of gravity bottom sampler. *Bull. Geol. Soc. Amer.*, 57, pp. 935–48.

JENKINS, J. T. 1921. *A textbook of oceanography.* London.

JOLY, J. 1908. On the radium content of deep-sea sediments. *Phil. Mag.*, 16, pp. 190–7.

JONES, O. T. 1937. On the sliding or slumping of submarine sediment in Denbighshire, North Wales, during the Ludlow period. *Quart. J. Geol. Soc. Lond.*, 93, pp. 241–83.

KARLIK, B. 1939. The uranium content of sea-water. *Göteborg. Vetensk-Samh. Handl.*, Földj. 5, ser. B, 6, No. 12, pp. 7–14.

KLUTE, F. 1928. Die Bedeutung der Depression der Schneegrenze für die eiszeitliche Probleme. *Z. Gletscherk.*, 16, pp. 70–93.

KOCZY, F. F. 1949. Thorium in sea-water and marine sediments. *Geol. Fören. Stockh. Förh.*, 71, pp. 238–242.

KUENEN, PH.H. 1935. Geological interpretation of bathymetrical results. "*Snellius*" *Exped.*, 5, 1, pp. 1–124.

————. 1942. Collecting of the samples and some general aspects. "*Snellius*" *Exped.*, 5, 3, pp. 1–46.

————. 1949. Slumping in the Carboniferous rocks of Pembrokeshire. *Quart. J. Geol. Soc. Lond.*, 104, pp. 365–85.

KULLENBERG, B. 1947. The piston core sampler. *Svenska hydrogr.-biol. Komm. Skr.* (3, Hydr.) 1, 2, pp. 1–46.

LADD, H. S., TRACY, J. I. and LILL, G. G. 1948. Drilling on Bikini Atoll, Marshall Islands. *Science*, 107, pp. 51–5.

LEROY, L. W. 1948. The foraminifer *Orbulina universa* d'Orbigny, a suggested Middle Tertiary time indicator. *J. Paleont.*, 22, pp. 500–8.

MACDONALD, G. A., SHEPARD, F. P. and COX, D. C. 1947. The tsunami of April 1, 1946, in the Hawaiian Islands. *Pacific Science*, 1, pp. 21–37.

MACDONALD, W. F. 1944. Atlas of climatic charts of the oceans. *Marine Observatory, U.S. Dept. Agric., Weather Bureau.* 130 maps.

MAURER, H. and STOCKS, T. 1933. Die Echolotungen des "*Meteor.*" *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess.* "*Meteor*" 1925–1927, B.2., 309 pp., 4 pls.

MAURY, M. F. 1855. *The physical geography of the sea and its meteorology.* London.

MEHMEL, M. 1939. Application of X-ray methods to the investigation of recent sediments. *In* Trask, P. "Recent marine sediments. A symposium," pp. 616–30. London.

MEINESZ, F. A. V. 1934. Gravity expeditions at sea 1923–1932, 2. *Publ. Netherlands Geodetic Comm.*, pp. 116–39.

————. 1948. Major tectonic phenomena and the hypothesis of convection currents in the earth. *Quart. J. Geol. Soc. Lond.*, 103, pp. 191–207.

————. 1948. Gravity expeditions at sea 1923–38, 4. *Publ. Netherlands Geodetic Comm.*, pp. 1–233.

MELLIS, O. 1948. The coarse grained horizons in the deep-sea sediments from the Tyrrhenian Sea. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 5, No. 13, pp. 47–72.

MORTIMER, C. H. 1941. The exchange of dissolved substances between mud and water in lakes. *J. Ecol.*, 29, pp. 280–329.

MÜLLER, E. 1938. Beitrage zur Frage der biochemischen Schichtung im Lunzer Ober und Untersee. *Int. Rev. Hydrobiol.*, 36, pp. 433–500.

MURRAY, H. W. 1941. Submarine mountains in Gulf of Alaska. *Bull. Geol. Soc. Amer.*, 52, pp. 333–62.

MURRAY, J. 1897. On the distribution of the pelagic foraminifera at the surface and on the floor of the ocean. *Nat. Sci. Lond.*, 65, pp. 17–27.

———— and REYNARD, A. F. 1891. Report of the scientific results of the voyage of H.M.S. *Challenger*. Deep-sea deposits.

MYERS, E. H. 1943. Life activities of foraminifera in relation to marine ecology. *Proc. Amer. Phil. Soc.*, 86, pp. 439–58.

NEEB, G. A. 1943. The composition and distribution of the samples. "*Snellius*" *Exped.*, 5, pp. 55–266.

NILSSON, E. 1949. The pluvials of East Africa. An attempt to correlate Pleistocene changes of climate. *Geogr. Ann., Stockh.*, 1–2, pp. 204–11 (Ahlmann Tribute Vol., *Glaciers and Climate* ; agents, John Murray, London).

ORBIGNY, A. D. D'. 1840. Mémoire sur les foraminifères de la Craie blanche du bassin de Paris. *Mém. Soc. Geol. Fr.*, 4, pp. 1–51, pls. i–iv.

OVEY, C. D. 1937. Some Tertiary foraminifera from Cyprus. *J. Roy. Micr. Soc.*, 57, pp. 106–34.

———. 1949. Contribution to discussion on "post-glacial climatic change." *Quart. J. Roy. Met. Soc.*, 75, pp. 182–4.

———. 1949a. Note on the evidence for climatic changes from sub-oceanic cores. *Weather*, London, 4, pp. 228–31.

PARKER, F. L. 1948. Foraminifera of the continental shelf from the Gulf of Maine to Maryland. *Bull. Mus. Comp. Zool. Harv.*, 100, pp. 213–41.

PEACH, B. N. 1912. Report on rock specimens dredged by the *Michael Sars* in 1910, by H.M.S. *Triton* in 1882, and by H.M.S. *Knight Errant* in 1880. *Proc. Roy. Soc. Edinb.*, 32, pp. 262–91.

PETTERSSON, H. 1930. Teneur en radium des dépôts de mer profonde. *Résult. Camp. Sci. Monaco*, 91, pp. 1–50.

———. 1943. Manganese nodules and the chronology of the ocean floor. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 2, No. 8, pp. 1–43.

———. 1948. *Rätsel der Tiefsee.* Bern.

———. 1948a. The Swedish deep-sea expedition. *Pacific Science*, 2, pp. 231–8.

———. 1948b. The radium content in three Tyrrhenian sediment cores. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 5, No. 13, pp. 89–94.

———. 1949. The geochronology of the deep ocean bed. *Tellus, Stockholm*, 1, pp. 1–5.

———. 1949a. Exploring the bed of the ocean. *Nature*, 164, pp. 468–70.

——— and KULLENBERG, B. 1941. Vakuumlodet. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 1, No. 10, pp. 1–16.

——— and RONA, E. 1939. The radium content of sea-water, *Göteborg. VetenskSamh. Handl.*, Földj. 5, ser. B, 6, No. 12, pp. 15–44.

PHILLIPI, E. 1908. Über das Problem der Schichtung und über Schichtbildung am Boden der heutigen Meere. *Z. dtsch. geol. Ges.*, 60, pp. 346–76.

———. 1910. Die Grundproben der Deutchen Südpolarexpedition 1901–1903. *Dtsch. Südpolar Exp.*, 2, 6 (Geogr. Geol.), pp. 411–616.

PHIPPS, J. C. 1774. *A voyage towards the North Pole.* London.

PHLEGER, F. B. 1939. Foraminifera of submarine cores from the continental slope. *Bull. Geol. Soc. Amer.*, 50, pp. 1395–1422.

———. 1942. Foraminifera of submarine cores from the continental slope, Part 2. *Bull. Geol. Soc. Amer.*, 53, pp. 1073–98.

———. 1945. Vertical distribution of pelagic foraminifera. *Amer. J. Sci.*, 243, pp. 377–83.

———. 1947. Foraminifera of three submarine cores from the Tyrrhenian Sea. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 5, No. 5, pp. 1–19.

———. 1948. Foraminifera of a submarine core from the Caribbean Sea. *Göteborg. VetenskSamh. Handl.*, Földj. 6, ser. B, 5, No. 14, pp. 1–9.

———. 1949. Submarine geology and Pleistocene research. *Bull. Geol. Soc. Amer.*, 60, pp. 1457–61.

——— and HAMILTON, W. A. 1946. Foraminifera of two submarine cores from the North Atlantic Basin. *Bull. Geol. Soc. Amer.*, 57, pp. 951–66.

PIGGOT, C. S. 1933. Radium content of ocean bottom sediments. *Amer. J. Sci.* (5) 25, pp. 229–38.

———. 1936. Apparatus to secure core samples from the ocean bottom. *Bull. Geol. Soc. Amer.*, 47, pp. 675–84.

——— and URRY, W. D. 1939. The radium content of an ocean bottom core. *J. Wash. Acad. Sci.*, 29, pp. 405–15.

——— ———. 1942. Time relations in ocean sediments. *Bull. Geol. Soc. Amer.*, 53, pp. 1187–210.

——— ———. 1942a. Radioactivity of ocean sediments, IV. The radium content of sediments of the Cayman Trough. *Amer. J. Sci.*, 240, pp. 1–12.

PRATJE, O. 1939. Die Sedimente des Südatlantischen Ozeans. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermiss.* "*Meteor*" 1925–1927, B.3, Tl.2, Lief.2, pp. 57–171.

RADCZWESKI, O. E. 1937. Die Mineralfazies der Sedimente des Kapverden Beckens. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess.* "*Meteor*" 1925–1927, B.3, Tl.3, Lief.2, pp. 262–77.

REVELLE, R. 1934. Physico-chemical factors affecting the solubility of calcium carbonate in sea-water. *J. Sediment. Petrol.*, 4, pp. 103–10.

————. 1940. Current measurements near the sea bottom. *Ass. Océanog. Union Géod. Géophys. Internat.*, Proces-verbeaux, No. 3, pp. 114–15.

————. 1944. Marine bottom samples collected in the Pacific Ocean by the *Carnegie* on its seventh cruise. *Publ. Carneg. Instn.*, 556, pp. 1–188.

———— and SHEPARD, F. P. 1939. Sediments off the Californian coast. *In* Trask, P. " Recent marine sediments. A symposium," pp. 245–82. London.

RIEL, P. M. VAN. 1934. Soundings and bathymetrical charts. "*Snellius*" *Exped.*, 2, pt. 2, chap. 2, pp. 1–63.

————. 1940. Netherlands. (Communication from members of the committee in response to circular letter.) *Union Géod. Géophys. Internat.*, Publ. Sci., 8, pp. 41–4.

ROSS, J. 1819. *A voyage of discovery . . . for the purpose of exploring Baffin's Bay.* London.

ROSS, J. CLARK. 1847. *Voyage of discovery and research in the Southern and Antarctic regions during the years 1839–43.* 1. London.

SANDERMAN, L. A. and UTTERBACK, C. L. 1941. Radium content of ocean bottom sediments from the Arctic Ocean, Bering Sea, Alaska Peninsula, and the coasts of southern Alaska and western Canada. *J. Mar. Res.*, 4, pp. 132–41.

SATTERLY, J. 1911. On the radium content of various fresh and sea-waters and some other substances. *Proc. Camb. Phil. Soc.*, 16, pp. 360–4.

SCHOTT, W. 1935. Die Foraminiferen in dem äquatorialen Teil des Atlantischen Ozeans. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess.* "*Meteor*" 1925–1927, B.3, Tl.3, pp. 43–134.

————. 1938. Über die Sedimentiongeschwindigkeit rezenter Tiefseesedimente. *Geol. Rdsch.*, 29, pp. 330–3.

SEWELL, R. B. SEYMOUR. 1935. Introduction and list of stations. *John Murray Exped.* 1933–34, *Sci. Rep.*, 1, pp. 1–41.

————. 1948. The free-swimming planktonic Copepoda. Geographical distribution. *John Murray Exped.* 1933–34, *Sci. Rep.*, 8, pp. 317–592.

SHAND, S. J. 1949. Rocks of the Mid-Atlantic Ridge. *J. Geol.*, 57, pp. 89–92.

SHEPARD, F. P. 1941. Nondepositional physiographic environments off the Californian coast. *Bull. Geol. Soc. Amer.*, 52, pp. 1869–86.

————. 1948. *Submarine geology.* New York.

———— and EMERY, K. O. 1941. Submarine topography off the Californian coast: canyons and tectonic interpretation. *Geol. Soc. Amer. Spec. Paper*, 31, 171 pp., 18 pls.

———— ————. 1946. Submarine photography off the Californian coast. *J. Geol.*, 54, pp. 306–21.

SIMPSON, G. C. 1940. Possible causes of change in climate and their limitations. *Proc. Linn. Soc. Lond.*, session 152, 1939–40, pp. 190–219.

SMITH, P. A. 1937. The submarine topography of Bogoslof. *Geogr. Rev.*, 26, pp. 630–6.

STETSON, H. C. 1933. Bottom deposits. Scientific results of the *Nautilus* Expedition, 1931. Papers in physical oceanography and meteorology, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, 2, No. 3, pt. 5, pp. 17–37.

STETSON, H. C. 1937. Bottom deposits of the Ross Sea. *J. Sediment. Petrol.*, 7, pp. 55–66.

————. 1949. The sediments and stratigraphy of the east coast continental margin : Georges Bank to Norfolk Canyon. Papers in physical oceanography and meteorology. Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, 11, No. 2, pp. 5–60.

STOCKS, T. 1937. Morphologie des Atlantischen Ozeans. Grundkarte der Ozeanischen Lotungen 1 : 5 Millionen, Blatt SII. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess. "Meteor"* 1925–1927, B.3, Tl.1, Lief.4(1).

————. 1939. *ibid.*, Blatt SI_2. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch, u. Vermess. "Meteor"* 1925–1927, B.3, Tl.1, Lief.4 (2).

————. 1941. *ibid.*, Blatt SII_1 and SII_3 *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess. "Meteor"* 1925–1927, B.3, Tl.1, Lief.4 (3 and 4).

————. 1941a. Die Tiefenverhältnisse des Golfs von Aden. *Z. ges. Erdk. Berl.*, pp. 207–21.

————. 1941b. Wie gross ist das Nordpolargebiet ? *Ann. Hydrogr. Berl.*, 1, pp. 25–8.

————. 1942. Zur Bodengestaltung der nordwestlichen Indischen Ozeans. *Z. ges. Erdk. Berl.*, 34, pp. 115–23.

———— and WÜST, G. 1935. Morphologie des Atlantischen Ozeans. Die Tiefenverhältnisse des Offenen Atlantischen Ozeans. *Wiss. Ergebn. dtsch. Atlant. Exped. Forsch. u. Vermess. "Meteor"* 1925–1927, B.3, Tl.1, Lief.1, pp. 1–32.

STUBBINGS, H. G. 1939. Stratification and biological remains in marine deposits. *John Murray Exped.* 1933–34 *Sci. Rep.*, 3, pp. 159–92.

SVERDRUP, H. U., JOHNSON, M. W. and FLEMING, R. H. 1942. *The oceans, their physics, chemistry and general biology.* New York.

TAYLOR, F. B. 1910. Bearing of the Tertiary mountain belt on the origin of the earth's plan. *Bull. Geol. Soc. Amer.*, 21, pp. 179–226.

TILLEY, C. E. 1947. The dunite-mylonites of St. Paul's Rocks (Atlantic). *Amer. J. Sci.*, 243, pp. 483–91.

TRASK, P. D. 1932. *Origin and environment of source sediments of petroleum.* Houston, Texas.

————. 1932a. Sediments. The *Marian* expedition to Davis Strait and Baffin Bay, 1928. *Bull. U.S. Cst. Guard*, 19, pp. 62–81.

————. 1937. Relation of salinity to calcium carbonate content of marine sediments. *U.S. Geol. Surv. Prof. Paper*, 186, pp. 273–99.

UMBGROVE, J. H. F. 1945. Different types of island arcs in the Pacific. *Geogr. J.*, 106, pp. 198–209.

————. 1947. *The pulse of the earth.* The Hague.

————. 1949. *Structural history of the East Indies.* Cambridge.

URRY, W. D. 1941. The radioactive determination of small amounts of uranium. *Amer. J. Sci.*, 239, pp. 191–203.

————. 1942. The radio-elements in non-equilibrium series. *Amer. J. Sci.*, 240, pp. 426–36.

————. 1949. Concentration of radio elements in marine sediments of the Southern Hemisphere. *Amer. J. Sci.*, 247, pp. 257–75.

———— and PIGGOT, C. S. 1942. Concentration of radioactive elements and their significance in red clay. *Amer. J. Sci.*, 240, pp. 93–103.

UTTERBACK, C. L. and SANDERMAN, L. A. 1938. Radium content of some inshore bottom samples in the Pacific Northwest. *J. Mar. Res.*, 1, pp. 187–91.

VAUGHAN, T. W. 1940. The classification and nomenclature of the submarine features of the Gulf of Mexico and the Caribbean Sea. *Union. Géod. Géophys. Internat.*, Publ. Sci., 8, pp. 61–76.

WASHINGTON, H. S. 1930. The petrology of St. Paul's Rocks (Atlantic). *In* "Report on the geological collections made during the voyage of the *Quest* on the Shackleton-Rowett expedition to the South Atlantic and Weddel Sea in 1921–2." London (British Museum).

————. 1930a. The origin of the Mid-Atlantic Ridge. *J. Md. Acad. Sci.*, 1, pp. 20–9.

WEGNER, A. 1924. *The origin of continents and oceans.* London.

WEIBULL, W. 1947. The thickness of ocean sediments measured by a reflexion method. *Göteborg. VetenskSamh. Handl.*, Foldj. 6, ser. B. 5, No. 4, pp. 7–17.

WICHMANN, A. 1902. Der Vulkan der Insel Una Una (Nangura) im Busem von Tomini Celebes. *Z. dtsch. geol. Ges.*, 54, pp. 144–58.

————. 1922. Die Vulkane der Sangi-Inseln. *Verh. Akad. Wet. Amst.*, 22, 1, pp. 1–52.

WILLETT, H. C. 1949. Long-period fluctuations of the general circulation of the atmosphere. *J. Met.*, 6, pp. 34–50.

————. 1949a. Solar variability as a factor in the fluctuations of climate during geological time. *Geogr. Ann. Stockh.*, 1–2, pp. 295–315 (Ahlmann Tribute Vol., *Glaciers and Climate* ; agents, John Murray, London).

WISEMAN, J. D. H. 1936. The petrography and significance of a rock dredged from a depth of 744 fathoms near to Providence Reef, Indian Ocean. *Trans. Linn. Soc. Lon., Zool.* (2) 19, pp. 437–43.

————. 1937. Basalts from the Carlsberg Ridge, Indian Ocean. *John Murray Exped.* 1933–34 *Sci. Rep.*, 3, pp. 1–30.

————. 1949. Geology of the deep-sea floor. *Nature*, 164, pp. 682–4.

———— and BENNETT, H. 1940. The distribution of organic carbon and nitrogen in sediments from the Arabian Sea. *John Murray Exped.* 1933–34 *Sci. Rep.*, 3, pp. 193–221.

———— and SEWELL, R. B. SEYMOUR. 1937. The floor of the Arabian Sea. *Geol. Mag.*, London. 74, pp. 219–30.

WÜST, G. 1939. Das submarine Relief bei den Azoren. *Abh. preuss. Akad. Wiss.*, 1939, 5, pp. 46–58.

————. 1940. Das Relief des Azorensockels und des Meeresbodens nördlich und nordwestlich der Azoren. *Ann. Hydrogr. Berl.*, August-Beiheft, Lief.2, pp. 1–19.

————. 1940a. Zur Nomenklatur der Grossformen der Ozeanböden. *Ass. Océanog. Union Géod. Géophys. Internat.*, Publ. Sci. No. 8, pp. 120–4.

ZEUNER, F. E. 1937. The climate of the countries adjoining the ice-sheet of the Pleistocene. *Proc. Geol. Ass.*, 48, pp. 370–95.

————. 1945. *The Pleistocene period ; its climate, chronology and faunal successions.* Ray. Soc., London.

EXPLANATION OF PLATES

PLATE 2

Recent cold and temperate water planktonic foraminifera :—

FIG. 1. *Globigerina dutertrei* d'Orb., (a) dorsal, (b) ventral, (c) apertural. views : from British Antarctic Expedition 1910, Station 171, 66°38′ S., 178°47′ W., 3593 m. (1964 fm.). (ZF. 1838).[1] x 45.

„ 2. *Globigerina pachyderma* (Ehr.), (a) dorsal, (b) ventral, (c) peripheral views : from F.C. *Goldseeker* Haul 123, Faroe Channel, 59°41′ W., 8° W., 850 m. (465 fm.). (ZF. 1839.) x 45.

---

[1] The letters ZF. followed by figures refer to registration numbers in the zoological collections of the British Museum (Natural History). The samples 1–9 used in the validity test are registered ZF. 2651–9 respectively.

Recent temperate water planktonic foraminifera:—

FIG. 3. *Globigerina bulloides* (d'Orb.), (a) dorsal, (b) ventral, (c) peripheral views: from F.C. *Goldseeker* Haul 123, Faroe Channel, 59°41′ N., 8° W., 850 m. (465 fm.). (ZF. 1841.) x 45.

„ 4. *Globorotalia canariensis* (d'Orb.), (a) dorsal, (b) ventral views: from *Challenger* Station 300, 33°42′ S., 78°18′ W., off Juan Fernandez, 2515 m. (1375 fm.). (ZF. 1826.) x 25.

„ 5. *Globigerina inflata* (d'Orb.), (a) dorsal, (b) ventral, (c) peripheral views: from F.C. *Goldseeker* Haul 123, Faroe Channel, 59°41′ N., 8° W., 850 m. (465 fm.). (ZF. 1840.) x 45.

„ 6. *Globorotalia hirsuta* (d'Orb.), (a) dorsal, (b) ventral, (c) peripheral views: from *Discovery* Exped., Mid-Atlantic, 26°07′40″ S., 14°36′20″ W., 3195 m. (1747 fm.). (ZF. 1825.) x 45.

„ 7. *Globorotalia truncatulinoides* (d'Orb.), (a) ventral, (b) dorsal, (c) peripheral views: from U.S.F.C. *Albatross* Station 2150, 13°34′45″ N., 81°21′10″ W., 699 m. (382 fm.). (ZF. 1827.) x 25.

„ 8. *Globorotalia crassula* Cushman & R. E. Stewart, (a) dorsal, (b) ventral, (c) peripheral views: from *Discovery* Exped., Mid-Atlantic, 26° 07′40″ S., 14°36′20″ W., 3195 m. (1747 fm.). (ZF. 1835.) x 45.

PLATE 3

Recent warm water planktonic foraminifera:—

FIG. 1. *Globorotalia menardii* (d'Orb.), (a) dorsal, (b) ventral, (c) peripheral views: from *Challenger* Station 224, 7°45′ N., 144°20′ E., 3383 m. (1850 fm.). (ZF. 1822).

„ 2. *Globorotalia tumida* (Brady), (a) dorsal, (b) ventral, (c) peripheral views: from *Challenger* Station 224, 7°45′ N., 144°20′ E., 3383 m. (1850 fm.). (ZF. 1824).

„ 3. *G. menardii* var. *fimbriata* (Brady), dorsal view: from U.S.F.C. *Albatross* Station 2150, 13°34′45″ N., 81°21′10″ W., 699 m. (382 fm.). (ZF. 1823.)

„ 4. *Sphaeroidinella dehiscens* (d'Orb.), ventral view: from *Challenger* Station 224, 7°45′ N., 144°20′ E., 3383 m. (1850 fm.). (ZF. 1828.)

„ 5. *Globigerinoides sacculifera* (Brady), dorsal view: from *Challenger* Station 224, 7°45′ N., 144°20′ E., 3383 m. (1850 fm.). (ZF. 1833.)

„ 6. *Orbulina universa* d'Orb. *Challenger* Station 224, 7°45′ N., 144°20′ E., 3383 m. (1850 fm.). (ZF. 1829.)

„ 7. *Pulleniatina obliquiloculata* (Parker & Jones), apertural view: from *Challenger* Station 218, S.W. Pacific, 1957 m. (1070 fm.). (ZF. 1837.)

„ 8. *Globigerinoides conglobata* (Brady), (a) dorsal, (b) ventral views: from *Challenger* Station 224, 7°45′ N., 144°20′ E., 3383 m. (1850 fm.). (ZF. 1831.)

„ 9. *Globigerinella aequilateralis* (Brady) var. *involuta* Cushman, (a) ventral, (b) peripheral views: from *Challenger* Station 224, 7°45′ N., 144° 20′ E., 3383 m. (1850 fm.). (ZF. 1830.)

„ 10. *Globigerina dubia* Egger, (a) dorsal, (b) ventral views: from U.S.F.C. *Albatross* Station 2150, 13°34′45″ N., 81°21′10″ W., 699 m. (382 fm.). (ZF. 1834.)

„ 11. *Globorotalia scitula* (Brady), (a) dorsal, (b) ventral, (c) peripheral views: from *Challenger* Station 302, 42°43′ S., 82°11′ W., 2652 m. (1450 fm.). (ZF. 1836)

„ 12. *Globigerinoides rubra* (d'Orb.), (a) dorsal, (b) ventral views: from U.S.F.C. *Albatross* Station 2150, 13°34′45″ N., 81°21′10″ W., 699 m. (382 fm.). (ZF. 1832.)

All specimens x 25, except Fig. 12, which is x 45.

DEMONSTRATION AT THE BRITISH MUSEUM (NATURAL HISTORY)

19th February, 1949

Report by : J. D. H. Wiseman and C. D. Ovey

[*Received 27th October*, 1949]

A DEMONSTRATION was held in the Shell Gallery at 2.30 on some problems concerning the deep-sea floor. After the Director had welcomed Professor and Mrs. Hans Pettersson, with whose company the party were honoured, Dr. J. D. H. Wiseman, Department of Mineralogy, gave a brief historical survey of the development of sounding and coring apparatus prior to the voyage of H.M.S. *Challenger*. He outlined various problems concerning the structure of sub-oceanic features with special reference to the flat-topped sea-mounts called guyots, and paid special attention to the Urry technique of determining the age of deep-sea cores by means of the non-equilibrium series, uranium, ionium, radium.

Mr. C. D. Ovey, Department of Zoology, outlined the significance of a study of planktonic foraminifera, discussed briefly the ecological problems involved in their distribution, and laid stress on the most important ecological factor, namely temperature. He demonstrated how use has been made of foraminifera in the interpretation of climatic fluctuations from deep-sea cores notably that taken by the *Albatross* in the Caribbean with the Kullenberg corer and worked out by Dr. F. B. Phleger. The importance of glacial marine deposits and their interdigitation with globigerina ooze was also stressed.

Professor Hans Pettersson was invited to address the company. After expressing his pleasure in addressing the Association in the Museum, he gave a short summary of the *Albatross* expedition and recalled many incidents which had occurred during the voyage. He stated that he hoped the scientific results of the examination of the deep-sea cores would be completed within five years.

The President thanked the speakers on behalf of the Association and expressed his delight that Professor Pettersson had surprised and honoured the Association with his company. He also expressed to the Director the great appreciation the Association felt towards him and the Trustees for the sympathy and assistance the Museum had so often given on various occasions. Tea was served and the exhibits were examined. These consisted of a series of oceanographical charts showing the evolution of deep-sea morphology ; a core obtained by the John Murray Expedition from the Arabian Sea ; a series of manganese nodules to illustrate their fragmentation on the deep-sea floor ; temperature-indicating planktonic foraminifera, and excellent photographs of their food, diatoms, taken with the electron microscope and kindly lent by Dr. N. Ingram Hendey; also a large number of deep-sea organisms, and historical records to illustrate the exploration of the deep-sea floor.

The demonstrators wish to express their thanks to their colleagues on the museum staff for their co-operation both in the preparation of the exhibits and for lending specimens under their charge.

THE ANNUAL REPORT OF THE COUNCIL OF THE GEOLOGISTS' ASSOCIATION FOR THE YEAR 1949

THE numerical strength of the Association on 31st December, 1949, was as follows :—

Honorary Members	18
Ordinary Members :—	
Life Members (compounded)	166
Annual Subscribers ..	1630
	1814

During the year 206 new members were elected, and the Association lost 81 members through death, resignation and removals under Rule XI for failure to pay subscriptions. The membership continues to rise, and shows an increase of 125 over that of the previous year.

The list of deceased members is as follows :—F. N. Ashcroft, Miss Emily Aston, P. Faulks, E. J. Garwood, J. F. N. Green, Mrs. R. S. Herries, W. F. Hume, L. H. Kemp, G. N. E. Kennett-Barrington, P. Lake, S. H. Reynolds and Sir T. Franklin Sibly.

Obituary notices will be published in the *Proceedings.*

FINANCE

On the Income side of the General Purposes Account admission fees and annual subscriptions show revenue of £850 10s. as compared with £826 in 1948, £712 in 1947, and £642 10s. in 1946. On the expenditure side of the Account, the cost of four parts of the *Proceedings* appears as £914 12s. 4d. as compared with £979 6s. 3d., the cost of five parts in 1948. The item of £329 shown as a transfer to a General Reserve Fund represents War Damage compensation for the loss of the Association's stock of printed publications, destroyed by enemy action on the night of 16th April, 1941.

The balances in the various Special Funds, apart from the Reserve Fund for Index and List of Members, amount to £817 10s. 3d. This sum is available for the general purposes of the Association, and is in addition to the accumulated fund of £137 12s. 7d. Gratitude is due to the Royal Society for the allocation of two grants of £200 each from the Parliamentary Grant in aid of Scientific Publications, one in respect of an application made in 1948 and the other in respect of a similar application made in 1949.

The general financial position of the Association may therefore be regarded as satisfactory.

Illustrations Fund

Contributions to the Fund amounted to £61 3s. 8d. from 119 members as compared with £99 3s. 4d. from 123 members in 1948, and £64 1s. from 97 members in 1947.

TRUST FUNDS

Foulerton Award Fund

An award of £10 has been made from the Foulerton Award Fund, and the balance remaining in the Fund at the end of the year was £22 0s. 2d.

G. W. Young Geological Investigation Fund

During the year a further grant of £25 was made to Mr. R. Casey in aid of his investigations in the Folkestone Beds. The balance of the Fund at the close of the year was £68 12s.

Henry Stopes Memorial Fund

At the Annual General Meeting, the bronze medal was presented to Mr. S. H. Warren. The balance remaining in the Fund at the end of the year was £19 15s. 2d.

PUBLICATIONS

Publications Committee.—The Committee consisted of the officers (seven) together with Dr. S. Buchan, Mr. A. J. Butler, Dr. G. W. Himus, Mr. C. D. Ovey, Mr. G. S. Sweeting and Mr. A. Wrigley. The Committee met on five occasions and considered 16 papers, upon which reports were made to the Council.

The Proceedings.—It has been possible this year to issue all four parts within the year. They contained 298 pages.

MEETINGS

Nine Ordinary meetings were held, at which five papers were read and three lectures were given.

The thanks of the Association are due to the Authors and Lecturers. The average attendance at meetings, 110, was well above that of last year.

The meetings were held at the apartments of the Geological Society of London, and Committee Meetings at the Imperial College of Science and Technology (Royal School of Mines).

The Association's thanks are due to the respective authorities for the facilities afforded.

REUNION

The Annual Reunion was held at the British Museum (Natural

History) on Saturday, 5th November. A number of interesting exhibits were shown, and the attendance exceeded that of last year. Thanks are due to the Director and Staff of the Museum and the members concerned.

A full account of this meeting will be given in the Report of the Session.

FIELD MEETINGS

The Committee consisted of the officers (seven) with Messrs. T. Barnard, F. H. Edmunds, G. W. Himus, C. D. Ovey, H. W. Pickworth, W. S. Pitcher, J. D. Weaver and M. K. Wells.

As the demands of the International Geological Congress prevented the normal number of Field Meetings being held in 1948, as full a programme as possible was arranged for 1949. In all, there were five half-day Demonstrations, six half-day, 11 whole-day, one weekend and the usual Easter, Whitsun and Summer Field Meetings. The only cancellation, owing to lack of support, was the proposed Summer Field Meeting in Portugal. The average attendance at the Field Meetings was half-day 23, whole-day 30, weekend 14, long 30. The Demonstrations were extremely well attended and in several cases there was insufficient room for all those who wished to be present.

The best thanks of the Association are due to the Directors and others who organised and assisted at the meetings. It is particularly satisfactory to record that amongst the Directors and Secretaries were a number who have given valuable help to the Association, after less than two years of membership.

Considering the enlarged membership of the Association, the attendance at the Field Meetings was scarcely as large as had been anticipated. This may be partly due to the high cost of coach and train fares. In an attempt to mitigate this, reduced party ticket fares were arranged whenever possible. However, the minimum number of eight for an official party was only reached on a third of the possible occasions. In view of the very considerable amount of extra work involved, and because some financial loss was caused to the Association, it is not proposed to continue with party ticket arrangements until there are firm indications that larger numbers of members will make use of them.

THE LIBRARY

The Library Committee consisted of the officers, together with Dr. S. Buchan, Dr. L. J. Chubb, Mr. R. V. Melville, Mr. G. S. Sweeting and Mr. J. Wilks, University College Librarian. Thanks are due to the donors of a number of books and pamphlets, listed in the *Proceedings*. The following overseas institutions have been added to the Exchange List :—

Belgium, Société Géologique de Belgique.

Brazil, Instituto Brasileiro de Geografia e Estatistica.
Germany, Geologisches Staatsinstitut, Hamburg.
Jugo-Slavia, Institut Géologique de l'Université de Belgrade.
Peru, Instituto Geológico.
Portugal, Servicos Geológicos de Portugal.
Spain, Instituto de Ciencias Naturales José de Acosta.
Sweden, Stockholms Högskola.
U.S.A., University of Missouri School of Mines and Metallurgy.

WEALD RESEARCH COMMITTEE

Progress is being made with several researches in the Weald, and this year Professor S. W. Wooldridge has read an account of his detailed and long continued work in the Fernhurst District. Mr. W. H. E. Rivett has discovered some Iguanodon bones near Ockley, Surrey, which have been presented to the British Museum.

NORTH-EAST LANCASHIRE GROUP

Chairman : J. Ranson, A.M.I.Min.E., F.G.S.

Secretary : D. H. Learoyd, B.Sc., F.G.S.

Committee : Mrs. Harrop, B.A., B.Sc., W. Ashworth, F.G.S., F.R.G.S., J. E. Carter, M.A., F. Harding, M.Sc., J. E. W. Rhodes, Ph.D., B.Sc., F.I.C., S. Westhead.

During the year four lectures were given and three field meetings were held. Particulars will be published in the Report of the Session.

MIDLAND GROUP

Chairman : A. L. Lyon, M.Inst. C.E., M.Inst. W.E., F.G.S.

Secretary and Treasurer : Miss Grace M. Bauer.

Committee : Professor L. J. Wills, Messrs. A. J. Aiers, W. G. Hardie, H. M. Sale, F. Smith.

During the year five Lecture Meetings were held at the Geological Department, the University, Birmingham, and there were four Field Meetings. Particulars will be published in the Report of the Session. The average attendance was 35.

Thanks are due to Professor Wills and Professor Shotton for the use of the Geology Department at the University for meetings.

NORTH STAFFORDSHIRE GROUP

The Council records with great pleasure the formation, during the year, of a new group of the Association having its headquarters at Stoke-on-Trent and known as the North Staffordshire Group. A full report of the meetings of the Group is published in the Sessions Report.

COUNCIL FOR THE PROMOTION OF FIELD STUDIES

The Association's representative on the Council for the Promotion of Field Studies reports that the four field centres of the C.P.F.S.—Dale Fort, West Pembrokeshire ; Malham Tarn, N.W. Yorkshire ; Flatford Mill, Essex ; and Juniper Hall, Mickleham, Surrey—are now all well equipped for study, research and residence all the year round. In all these areas there is ample scope for geological study and research, and a particular need for geological collaboration in ecological and biological research problems under investigation.

TRUSTEES

The Trustees of the Association are :—

Managing : Mr. S. Hazzledine Warren, F.G.S., Dr. W. F. Fleet, M.Sc., A.R.I.C., A.C.P., F.G.S., and Mr. E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S.

Custodian : The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD

The Foulerton Award for the year was given to Mr. E. M. Venables, F.G.S., for work of merit connected with the Association.

HOUSE LIST

Mr. E. Ernest S. Brown retires as President, having guided the affairs of the Association through the past two years with the same devotion and loyalty which characterised his previous service of 12 years as General Secretary.

Mr. G. S. Sweeting retiring from the office of Vice-President completes 29 years continuous service as officer and member of the Council of the Association.

Dr. Vernon Wilson and Mr. F. W. H. Migeod retire as Ordinary Members of Council. The following resignations are much regretted : Mr. Dack, owing to personal reasons, from the office of Treasurer, and Dr. Kirkaldy, owing to pressure of other work, from the office of Field Meetings Secretary. Thanks are due to these members for services rendered to the Association.

ACCOUNTS FOR THE YEAR ENDING DECEMBER 31st, 1949

GENERAL PURPOSES ACCOUNT

INCOME

	£	s.	d.	£	s.	d.
To Admission Fees :—						
Received for 1949 Elections	84	10	0			
Received for Arrears	15	10	0			
	100	0	0			
Less Arrears at December 31st, 1948, £24, estimated to realise	20	0	0			
	80	0	0			
Add Arrears at December 31st, 1949, £20 10s., estimated to realise	12	0	0			
				92	0	0
To Annual Subscriptions :—						
(1) Received in 1944, 1945, 1946 and 1947 for 1949	4	0	0			
(2) Received in 1948 for 1949	93	0	0			
(3) Received in 1949 for 1949	628	0	0			
(4) Received in 1949 for arrears	38	10	0			
	763	10	0			
Less Arrears at December 31st, 1948, £87, estimated to realise	40	0	0			
	723	10	0			
Add Arrears at December 31st, 1949, £85 10s., estimated to realise	35	0	0			
				758	10	0
To Royal Society Grant, 1948				200	0	0
„ Royal Society Grant, 1949				200	0	0
„ Sale of Publications				198	4	0
„ Miscellaneous receipts				3	7	2
„ War Damage Payment				396	18	10
„ Transfer from other Accounts :—						
From Henry Stopes Memorial Fund to recoup cost of medal				2	0	0
„ Reserve Fund for Index and List of Members				115	17	9
				£1,966	17	9

EXPENDITURE

	£	s.	d.	£	s.	d.
By "Proceedings" of the Association (Vol. 59, Part 4, and Vol. 60, Parts 1, 2 and 3) :—						
(1) Printing	652	19	6			
(2) Illustrations	226	8	7			
(3) Authors' separate copies	35	4	3			
				914	12	4
„ Printing Monthly Circulars				130	3	3
„ Printing New List of Members				115	17	9
„ Stationery				84	4	10
„ Expenses at Meetings				35	19	0
„ Expenses at Field Meetings				5	12	1
„ Addressing and Stock-keeping				25	10	4
„ Postages				153	13	0
„ Insurance				1	16	0
„ Incidental Expenses				6	18	5
„ Yearly transfer to Reserve Fund for Index and List of Members				150	0	0
„ Transfer to General Reserve Fund				329	0	0
„ Excess of Income over Expenditure				13	10	9
				£1,966	17	9

BALANCE SHEET, DECEMBER 31st, 1949

LIABILITIES

	£	s.	d.	£	s.	d.
To Annual Subscriptions received in advance :—						
In 1944 for 1950/51	1	0	0			
In 1947 for 1950	1	0	0			
In 1948 for 1950/54	5	0	0			
In 1949 for 1950	85	0	0			
In 1949 for 1951/54	4	0	0			
				96	0	0
,, Sundry Creditors :						
Messrs. Benham & Co. Ltd.				28	4	8
,, Special Funds :						
Illustrations Fund	84	11	1			
Illustrations Fund (Capital)	20	0	0			
Reserve Fund for Index and List of Members	150	2	3			
Compounding Fund	1,868	4	1			
Bequest Funds	790	1	8			
General Reserve Fund	329	0	0			
				3,241	19	1
				3,366	3	9
Accumulated Funds at January 1st, 1949	124	1	10			
Add Excess of Income over Expenditure for the year	13	10	9			
				137	12	7
				£3,503	16	4

ASSETS

	£	s.	d.	£	s.	d.
By Investments (Special Funds) at cost or value when acquired :—						
,, Bequest Funds—						
£143 8 9 3½% War Stock	141	14	0			
£150 New Zealand 3⅛% Stock, 1960/64	122	5	0			
£285 3% Defence Bonds	285	0	0			
£100 3% Savings Bonds, 1960/70	100	0	0			
				648	19	0
,, Compounding Fund—						
£1,217 2 6 Nottingham Corporation 3% Irredeemable Stock	1,152	13	2			
£200 3% Savings Bonds, 1955/65	200	0	0			
£170 3½% War Stock	152	14	5			
£100 3% Savings Bonds, 1965/75	100	0	0			
				1,605	7	7
,, Illustrations Fund (Capital)—						
£21 0 10 Metropolitan Water Board 3% B Stock				20	0	0
,, Annual Subscriptions in Arrears, £85 10s., estimated to realise				35	0	0
,, Admission Fees in Arrears, £20 10s., estimated to realise				12	0	0
,, Cash at Bankers and in hand :						
At Bankers	178	2	5			
In Office	36	14	10			
				214	17	3
,, Special Funds :						
Illustrations Fund at Bankers	84	11	1			
Compounding Fund at Bankers	262	16	6			
Reserve Fund for Index and List of Members at Bankers	150	2	3			
Bequest Funds at Bankers	141	2	8			
General Reserve Fund at Bankers	329	0	0			
				967	12	6
				£3,503	16	4

SPECIAL ACCOUNTS

ILLUSTRATIONS FUND

	£	s.	d.
To Balance in hand on January 1st, 1949	22	14	11
,, Donations and Subscriptions	61	3	8
,, Transfer from Illustrations Fund (Capital)		12	6
	£84	11	1

	£	s.	d.
By Balance December 31st, 1949, at Bankers	84	11	1
	£84	11	1

SPECIAL ACCOUNTS (*continued*)

ILLUSTRATIONS FUND (CAPITAL)

		£ s. d.		£ s. d.
To Balance in hand on January 1st, 1949		0 0 0	By Transfer to Illustrations Fund	12 6
„ Dividends as received :—			„ Balance December 31st, 1949	0 0 0
£21 0 10 Metropolitan Water Board 3% B Stock ...		12 6		
		£0 12 6		£0 12 6

COMPOUNDING FUND

	£ s. d.	£ s. d.		£ s. d.
To Balance in hand on January 1st, 1949		157 14 8	By Balance December 31st, 1949, at Bankers	262 16 6
„ Composition Fees received during the year		53 12 8		
„ Dividends as received :—				
£1,217 2 6 Nottingham Corporation 3% Stock	36 10 2			
£170 0 0 3½% War Stock	5 19 0			
£300 0 0 3% Savings Bonds	9 0 0			
		51 9 2		
		£262 16 6		£262 16 6

RESERVE FUND FOR INDEX AND LIST OF MEMBERS

		£ s. d.		£ s. d.
To Balance in hand on January 1st, 1949		116 0 0	By Transfer to General Purposes Account for New List of Members...	115 17 9
„ Yearly Reservation for 1949		150 0 0	„ Balance December 31st, 1949, at Bankers	150 2 3
		£266 0		£266 0 0

BEQUEST FUNDS

	£ s. d.	£ s. d.		£ s. d.
To Balance in hand on January 1st, 1949		119 6 2	By Balance December 31st, 1949, at Bankers	141 2 8
„ Dividends as received :—				
£143 8 9 3½% War Stock	5 0 6			
£150 0 0 New Zealand 3½% Stock	5 5 0			
£285 0 0 3% Defence Bonds	8 11 0			
£100 0 0 3% Savings Bonds, 1960/70 ...	3 0 0			
		21 16 6		
		£141 2 8		£141 2 8

GENERAL RESERVE FUND

	£ s. d.		£ s. d.
To War Damage Compensation	329 0 0	By Balance December 31st, 1949, at Bankers	329 0 0

"TRUST" FUNDS

FOULERTON AWARD FUND

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1949	18	13	3	By Award to E. M. Venables, F.G.S.	10	0	0
,, Dividends as received :				,, Balance 31st December, 1949, at Bankers	22	0	2
£349 7 0 British Transport 3% Guaranteed Stock ...	5	15	2				
,, Income Tax repayment for 1948/49	7	11	9				
	£32	0	2		£32	0	2

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1949	85	17	6	By Grant to R. Casey, F.G.S.	25	0	0
,, Income for 1949, received from the Public Trustee...	5	6	2	,, Income Tax repayment paid to Public Trustee	3	15	10
,, Income Tax repayment for 1948/49	6	4	2	,, Balance 31st December, 1949, at Bankers	68	12	0
	£97	7	10		£97	7	10

HENRY STOPES MEMORIAL FUND

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1949	14	3	2	By Bronze Medal presented to S. H. Warren, F.G.S.	2	0	0
,, Dividends as received :				,, Engraving medal		7	6
£265 19 2 Government of Newfoundland 3% Stock, 1943/63	4	7	10	,, Balance 31st December, 1949, at Bankers	19	15	2
,, Income Tax repayment for 1948/49	3	11	8				
	£22	2	8		£22	2	8

We have compared these statements with the books and accounts presented to us and find them to agree.

We have also verified the investments of £1,217 2 6 Nottingham Corporation Stock, £200 3% Savings Bonds, 1955/65 £100 3% Savings Bonds, 1965/75, and, £170 3½% War Stock of the Compounding Fund, £349 7 0 British Transport 3% Guaranteed Stock, 1978/88, of the Foulerton Award Fund, £143 8 9 3½% War Stock, £150 New Zealand 3½% Stock, 1960/64, £285 3% Defence Bonds and £100 3% Savings Bonds, 1960/70, of the Bequest Funds ; £21 0 10 Metropolitan Water Board 3% B Stock of the Illustrations Fund (Capital), and £265 19 2 Government of Newfoundland 3% Stock, 1943/63, of the Henry Stopes Memorial Fund.

W. DACK, *Treasurer.*

28*th January*, 1950.

H. PICKWORTH
W. S. PITCHER } *Auditors.*

REPORT OF THE SESSION, 1949

Ordinary Meeting, *7th January*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Charles Geoffrey Adams, Miss Aries Aitken, Philip Brayford, Peter Cotterill, George Henry Anthony Edwards, Sir Alfred Leicester Saint Barbe Harmsworth, Bt., B.A., Charles Albert Vivian Haynes, David Nixon Holt, Herbert Homeshaw, Mark L. Larman, Richard Lee, Douglas MacLean Clark Macewan, Derek Maishman, John Kenneth Marshall, William E. H. Matthews, Arthur William Moffatt, Christopher Azubuike J. Onwuegbuzia, Kenneth Varnam Phillips, James Robinson, Peter Karel Sartory, Edward Arthur Stephens, Richard John Taunton, and Reginald Frank Leslie White were elected Members of the Association.

Dr. T. Barnard and Mr. H. W. Pickworth were elected auditors of the accounts for 1948.

The following papers were read :—" The Origin of Certain Rock-Structures near Aberystwyth," by J. Challinor, M.A. ; " The Lower Corallian Rocks of the Yorkshire Coast and Hackness Hills," by Vernon Wilson, Ph.D., M.Sc., D.I.C., A.M.I.M.M., F.G.S.

Ordinary Meeting, *4th February*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Harold Bowman-Beer, M.Sc., Edward William Herbert Culling, Joseph Gibbins Dufty, F.R.M.S., Timothy Douglas Fuller, Frank Howitt, John Knight, and Margaret Elsie Marsh were elected Members of the Association.

The following lecture was delivered :—" Some Aspects of the Geomorphology of the Ingleborough and Malham Area, N.W. Yorkshire," by Marjorie M. Sweeting, M.A., Ph.D.

Annual General Meeting, *4th March*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

The Annual Report of the Council (already circulated) was taken as read. It was moved by Dr. R. W. Pocock and seconded by Mr. M. K. Wells, " That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1948." The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of the Council in accordance with Rule XIII : President, E. Ernest S. Brown, M.B.E., F.G.S. ; Vice-Presidents, G. S. Sweeting, D.I.C., F.G.S., E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S., A. Wrigley, G. W. Himus, Ph.D., M.I.Chem.E., F.G.S., A. G. Bell, I.S.O., B.Sc., F.G.S. ; Treasurer, W. Dack, I.S.O., F.G.S. ; Secretaries, General—R. Reeley, F.G.S., Field Meetings—J. F. Kirkaldy, D.Sc., F.G.S., Publications Committee—A. J. Bull, Ph.D., M.Sc., F.G.S. ; Editor, K. S. Sandford, M.A., D.Sc., D.Phil., F.G.S. ; Librarian, L. R. Cox, M.A., Sc.D., F.G.S. ; twelve other Members of the Council, Miss M. A. Arber, M.A., F.G.S., F.R.G.S., T. Barnard, B.Sc., Ph.D., D.I.C., F.G.S., S. Buchan, B.Sc., Ph.D., F.G.S., A. J. Butler, O.B.E., M.Sc., F.G.S., T. Eastwood, A.R.C.S., F.G.S., F. W. H. Migeod, F.R.G.S., F.R.A.I., C.D. Ovey, B.Sc., F.G.S., Miss Mabel Tomlinson, B.A., D.Sc., Ph.D., F.G.S., J. D. Weaver, D. Williams, M.Sc., Ph.D., B.E., F.G.S., Vernon Wilson, M.Sc., Ph.D., D.I.C., A.M.I.M.M., F.G.S., C. W. Wright, M.A., F.G.S.

It was moved by Miss Elsie White, seconded by Mr. S. Theokritoff, and duly carried, " That the best thanks of the Association be given to the Officers, retiring members of Council and the Auditors."

Professor Herbert Leader Hawkins, D.Sc., F.R.S., F.G.S., was elected an Honorary Member of the Association.

The Foulerton Award was presented to Mr. E. M. Venables, F.G.S., in recognition of work of merit connected with the Association.

The President said :—

Mr. Venables,

For more than 25 years you have been an enthusiastic, amateur worker on the fauna and flora of the London Clay of Sussex. With much perseverance you have collected fossils from local sections and from the foreshore, recording your finds precisely from definite, limited horizons. You have also extended your work to the Bracklesham Beds of Selsey, to other Tertiary Beds elsewhere in the Hampshire Basin and to the Chalk of Felpham. In the course of this work you have developed your own technique for the extraction and preservation of difficult material.

Your work has been recorded in papers and reports published in our *Proceedings* and particularly in your papers on The London Clay of the Bognor District in 1929 and Notes on the Geology of Felpham in 1931.

You have directed a number of Field Meetings and for many years you have exhibited at our Annual Reunions large and well-arranged selections from your collection of fossils.

Moreover you have freely communicated the results of your work to specialists in Eocene palaeontology and you have presented many specimens to the British Museum (Natural History).

The Council of the Association has, therefore, bestowed on you the Foulerton Award for 1949 for " work of merit connected with the Association." As an amateur worker on the Eocene myself, I am particularly happy that the duty falls to me to hand you the Award this evening.

The Henry Stopes Memorial Medal was presented to Mr. S. Hazzledine Warren, F.G.S., in recognition of his work on the Prehistory of Man.

The President said :—

Mr. Hazzledine Warren,

The award to you by the Council of the Association of the second Henry Stopes Memorial Medal in recognition of your work " on the Prehistory of Man and his geological environment " provides a welcome opportunity not only to refer to your work on that subject but also to your long and intimate connection with the Association.

The extent and importance of your work on the Pleistocene is typified by your discovery of the Arctic Bed at Ponders End and your long continued research on a Late Glacial Stage in the Valley of the River Lea (*Quart. Journ. Geol. Soc.* 1912, 1915 and 1923). Again, your discovery and recognition of a palaeolithic flint industry, the Clactonian, previously unknown in this country, was an important advance in our knowledge of the Prehistory of Man. (*Proc. Prehistoric Soc. East Anglia*, 1922.) Your archaeological work has covered all cultural periods from the palaeolithic to the medieval and your investigations and conclusions are recorded in many contributions to the literature of prehistory.

Further, your critical approach to certain aspects of your subject has been of great value. As early as 1906 you gave the Association a lecture on " The pressure Chipping of Flint and the Question of Eolithic Man " and subsequently you led several field meetings to demonstrate how flint flaking may be caused *in situ* by natural forces. Finally, the need for caution in accepting flakes and chipped flints, as artefacts was emphasised in your Presidential Address in 1923 on " Sub-Soil Pressure Flaking." I well remember the controversies that raged at that time when, for example, nearly half the exhibits at our Annual Reunions were eoliths, rostrocarinates and flakes of uncertain origin. I was sure of only two things, the complete belief by every exhibitor in the human fabrication of his own specimens and an equally profound disbelief in the authenticity of all others.

Again, on the subject of Pleistocene Classification your second Presidential Address in 1924 called attention to the extraordinarily diverse views on correlation held by the leading authorities. In your Table of Comparative Pleistocene Classifications, published with that Address, 14 authorities are quoted and it was significant that agreement could be found only with the position of the Pliocene Crag at the base of your table. Later and more elaborate comparative tables have been published by other workers, with but little advance towards agreement. It would seem that only the Pre-Cambrian vies with the Pleistocene in diversity of correlations. The concluding remark of your Address remains the best advice today, i.e., " we need less theory and more facts."

You were elected a Member in 1897 and an Honorary Member in 1933 in recognition of your services to the Association, which included the arduous work of Treasurer for seven years (1914-21). During your Presidency you were the Leader of a party of our members to the Dordogne and your enthusiasm on that occasion is recalled in your Report of that visit. (*Proceedings* 1924.)

By reason, therefore, of your life's work on Pleistocene geology, on the Prehistory of Man and your work for the Association, we are delighted to honour you this evening by the presentation of the second Henry Stopes Memorial Medal.

Mr. Hazzledine Warren replied :—

Mr. President,

It is with a deep sense of gratitude and pleasure that I receive the Henry Stopes Memorial Medal from your hands.

You refer in too flattering terms to my work in prehistory ; I have only pleased myself in the endeavour to discover the true facts, and to follow without prejudice, fear or favour, the conclusions to which they point. One does not expect to be right in everything, and how far my results may prove to be broadly sound the future will decide.

I am particularly pleased that you quote with approval some words of advice I once expressed, namely, that we need " less theory and more fact," as I have honestly aimed at putting that into practice myself.

You also speak in very kind terms of my lecture on Flint Flaking delivered to the Association in 1906. I well remember the derision with which my unorthodox views were greeted at the time. Those hectic days of the

Eolithic controversy used to remind me of the lines of Bret Harte in which he describes one of the early meetings of an American Geological Society. He tells how one of the speakers was abruptly arrested in the spate of his eloquence:

"... when
A chunk of Old Red Sandstone caught him in the abdomen,
He smiled a kind of sickly smile, and lay upon the floor,
And subsequent proceedings interested him no more."

At one time it may be a chunk of Old Red Sandstone, at another a rostro-carinate, or it may be a poor Yorick's skull from Sussex, but these little pyrotechnic displays are all in the day's work. They are more than compensated by the other side, as many from whom one has differed theoretically have remained life-long friends, and one particularly values the good feeling of one's opponents.

If I have in past years done some little work for the benefit of the Association this has been generously repaid by the many happy and delightful personal contacts that resulted.

Occasions such as this make one look back on one's past life, and thus to recall that the first worked flint I ever found was on Edinburgh Castle rock in 1889. I was not long in finding out that it was a gun-flint, and thus to learn the need for a critical approach to the subject, that is to say, that flaked flints are not all prehistoric.

My first interest in Geology has always been mainly focused on the side of practical field work, an aspect of the subject which is so admirably fostered by the Field Meetings of our Association, which I constantly attended in my younger days.

It is therefore with a very special sense of gratification that I thank you, Mr. President, and the Association, for this valued recognition of my work, and for the great honour that you have conferred upon me.

The President then delivered his address entitled " Work for Amateur Geologists."

It was moved by Mr. C. D. Ovey, seconded by Mr. W. E. Howorth, and duly carried " That the best thanks of the Association be accorded the President for his Address."

Ordinary Meeting, 4*th March*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

David Francis Ball, Henry Burnip, Miss Agnes Elizabeth Bamber, M.Sc., F.G.S., John Francis Beck, M.I.Q., Maxwell Clinton Cater, Miss Renee Eugenie Coleman, Arthur George Cooper, John Emmanuel Cudjoe, Adam Sebastian Curtis, Miss Clare Isobel Fell, Frederick Clement Gee, John William Hobday, M.I.Q., Joseph Arthur Kent, Douglas Steven Macrae, William Russell, Fred Moore, John Barry Sullivan, Eric A. Tait, Keith Alan Viewing, Miss Eunice Lois Dorothy Willis, and George Alan Worrall, B.Sc., were elected Members of the Association.

Ordinary Meeting, 1*st April*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

William John Baker, Alan Ormandy Brown, John Elton Carter, Richard Peter Kelvin Clark, Walter Clews, Andrew Miller Fairlie, James Gregg, Cyril Lionel Hall, Dudley Gordon Hillier, Charles Hepworth Holland, George Harry Edward Hornbrook, James

Dixon Lawson, Peter Alan Moore, B.Sc., A.R.C.S., Christopher George Falkiner Nuttall, James Robertson, Edward Phillips Saggerson, Miss Lorna Ogilvie Scott, R. R. Sukhrani, B.E., Peter Thomson, Arthur Raymond Tron, James Robin Watson, B.Sc., John Thomas Wattison, Alan John Welch, Richard George Selby Westbury, Cyril Baxter Williamson, and Joseph Andrew Wright were elected Members of the Association.

The following lecture was delivered :—" Geology Today," by C. E. N. Bromehead, B.A., F.G.S.

Ordinary Meeting, 6*th May*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Frederick Thomas Banner, Arthur Clive Bishop, Kevin Charles Burke, Herbert Joseph Monro Clarke, Geoffrey Frederick Cowlin, George Harry Dury, M.A., Ian Graham Gass, Hubert Hitchon, Mendl Jacobs, William Fred Jones, Miss Barbara Kerr, Miss Ivy Winifred Kerslake, Feliks M. Kicinski, Archibald Lamont, M.A., Ph.D., Miss Josephine Patricia Lynch, Archibald McLean, Roy Harold Merley, John Newbery, Miss Hilary Ann Newton, Nicholas Rast, Roye William Rupert Rutland, Victor Gordon Walmsley, John Ralph Watkins, Herbert William Harcourt West, Ralph Whitman Williams, and Iain Ashworth Williamson were elected Members of the Association.

The following paper, by P. E. Kent, B.Sc., Ph.D., F.G.S., " A Structure Contour Map of the Pre-Permian Rocks of England and Wales," was read by Mr. F. D. S. Richardson, in the absence of the author overseas.

The following paper was " taken as read " : " The Ostracod *Cypridea* and the Zones of the Upper and Middle Purbeckian," by P. C. Sylvester-Bradley, B.Sc., F.G.S.

Ordinary Meeting, 10*th June*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Maurice l'Anson, Rudolf Geoffrey Waldemar Brunstrom, David Joseph Burdon, B.Sc., B.E., A.M.I.M.M., F.G.S., Richard Ernest Burtt, Thomas Morley Cobern, Gerard George Cole, Frederick Hutley Davey, Robert Arthur Eden, John Elliott, Frank John Fitch, John George C. M. Fuller, Francis Roger Spencer Henson, Miss Elizabeth Mary Hignett, B.Sc., Robert Eric Linton, Kenneth Ernest Lewis Nicholas, Brian John Reeley, Louis Rollason, Philip Edward Sells, John Solari, and Gerlad Wickens were elected Members of the Association.

The following paper was read :—" Some Features of the Structure and Morphology of the Country around Fernhurst, Sussex," by Professor S. W. Wooldridge, D.Sc., F.G.S.

Ordinary Meeting, 1*st July*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Patrick John Anderson, George Peter Askew, John Clifford

Blanchard, B.Sc., John Neil Bower Breakwell, Antony Santer Brown, Raymond Davies, Clive John Vivian Denning, Peter Dyson, Raymond Patterson Heppell, and David Arthur Wright were elected Members of the Association.

The following paper was read :—" Denudation Chronology of the Dip-slope of the South Downs," by B. W. Sparks, B.A.

An abnormal chalk foraminifer was exhibited by T. Barnard, Ph.D., B.Sc., F.G.S.

Ordinary Meeting, *5th November*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Leonard John Allchin, Henry Charles Turquand Brown, Frederick Thomas Burnett, Frederick Sydney Clark, Miss Jane F. Ekbery, B.A., Richard Edwin Roylance Evans, William Edmund Farenden, Frank Seymour Hulford, Peter John Jones, Miss Audrey Naylor, Mrs. Ethel May Parkinson, Ivor Morris Price, Alfred Riedel, Miss Enid Mary Smedley, M.Sc., Norman Thompson, John Bernard Williams, and Philip Frank Wraight were elected Members of the Association.

The Re-union, which followed, was held in the Shell Gallery of the British Museum (Natural History). For List of Exhibits, see below.

Ordinary Meeting, *2nd December*, 1949.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

William Herbert Ball, Geoffrey Weston Barlow, James Bell, John Norman Bone, Anthony Vernon Bradshaw, B.Sc., A.R.S.M., Geoffrey Riddle Burgess, Thomas Patrick Burnaby, John Alan Coker, Michael Edward Cosgrove, Jeffrey Cotterell, Denis Peter Drew, Denis Keith Ebdon, Thomas James Evans, Miss Pamela Fowler, Frederick Goldring, Reginald Francis Goodfellow, A.M.I.Struct.E., William Daniel Gill, B.Sc., Henry Claud Grant, B.Sc., F.Z.S., Peter Bredford Michael Handscomb, Miss Constance Hatelie, Miss Eva Gladys Henstock, David Hicks, Raymond Douglas Hockey, Leonard Hodgkinson, Peter Michael Howell, Edward Irving, A. Donald Johnson, F.G.S., M.I.M.E., A.M.I.C.E., Neville Jones, Gilbert Powell Larwood, Robert Edwin Lawrence, Anthony Ernest Lee, James Edward Ford Longman, George Griffiths Lovatt, Arthur Murray Packington, Henry Lawrence Ebden Newton, Miss Anne P. W. Nightingale, Ellis Frederic Owen, Edwin Thompson Pierce, Thomas Cecil Price, James Samuel Russell Redman, Arthur Eden Rixon, John Bernard Rolison, Roy George Sydney Smart, Gordon Douglas Smith, Maurice Bernard Stedman, B.A., M. W. Strong, Brian Taylor, John Totterdell, Thomas George Vallance, Mrs. Alice May Venables, Stanley Ware, Miss Barbara Katharine Whitaker, B.Sc., George Vincent Wood, and William Bernard Wright were elected Members of the Association.

The following lecture was delivered :—" Gravitational Sliding," by A. J. Bull, Ph.D., F.G.S.

LIST OF EXHIBITS

British Museum (Natural History)

(a) Early uses of fossils. (K. P. Oakley.)
(b) The Tertiary and Recent tree *Metasequoia*. (W. N. Croft.)
(c) Quaternary megaspores possibly derived from the Carboniferous. (M. E. J. Chandler and W. N. Croft.)
(d) Use of acids in the preparation of vertebrate fossils. (H. A. Toombs and A. E. Rixon.)
(e) Fossil Primates from Africa. (A. T. Hopwood.)
(f) Dinosaur Bones from Surrey. Collected and presented by W. H. E. Rivett.
(g) Recent publications.

Geological Survey and Museum

(a) Fossils from the Whittington, Nr. Lichfield, boring. (Palaeontological Dept.)
(b) Recent publications.

University College (Geology Dept.)

Demonstrations of Field Work.

Queen Mary College (Geology Dept.)

Specimens collected by members of the Department during the past year.

E. P. Bottley

(a) Some exceptionally fine groups of mineral crystals.
(b) New find of fossil fish in Italy.
(c) New student's petrological microscope.
(d) New research petrological microscope.
(e) Reflecting light single stage goniometer for student work.
(f) New prospector's (battery operated ; scheelite-fluorescing) U.V. light lamp.

Bottley, Mrs. W. E.

Carvings in semi-precious stones.

Carreck, J. N.

(a) Fossils from the Portland Stone of the Isle of Portland.
(b) Implements of flint and chert from Southern England.

Casey, R.

Lower Albian ammonites from Surrey and Sussex.

Cox, Miss H. M. M.

Collection of rocks and fossils from Bornholm.

Curry, D.

Fossils from the "Milford Marine Bed," Headon Beds, Milford-on-Sea, Hants.

Davis, A. G. and Wrigley, A.

London Clay fossils from Lower Swanwick, near Southampton.

Evans, E.

Photographs illustrating the geomorphology of a part of the Middle Thames.

Grimsdale, T. F.

Decalcified thin sections of Foraminifera, recent and fossil.

Hayward, J. F.

Some interesting rock specimens.

Heap, W.

New discoveries of Mesozoic Mammals in Durdlestone Bay, Swanage, Dorset.

Himus, G. W.

(a) Holograph letter by Mary Anning on the Lyme Regis Landslip of 1839.

(b) Proof of the four plates of fossils from Lyell's *Principles of Geology*, First Edition.

Jones, Francis

(a) A freak concretion from Drift at Guilsfield, Nr. Welshpool.

(b) Kodachrome transparencies illustrating British Geology.

Macfadyen, W. A.

Sandy gypsum crystals grown in 2-metre Raised Beach at El Batalaleh, Near Berbera, British Somaliland.

Marston, A. T.

Series of artefacts from 30-metre terraces. Tarn et Garonne (France).

Rivett, W. H. E.

Dinosaur remains from Surrey.

Stinton, F. C.

Vertebrate remains from the Oligocene of the Hampshire Basin.

Venables, E. M. and Turner, J. G.

Fossils from Bracklesham Bay.

Venables, E. M.

Fossil beetles of the London Clay.

Wells, A. K.

Rock specimens from, and photographs of, Western Norway.

Wright, C. W. and Wright, E. V.

(a) Australian Tertiary Echinoids.
(b) New Zealand Senonian Ammonites.
(c) South African Neocomian fossils.
(d) Recent English Cretaceous finds.

FIELD MEETINGS

The following meetings took place :—

Saturday, 15th January.—Thirty members attended a demonstration at Kew Observatory.

Saturday, 19th February.—There was an attendance of at least 150 at a demonstration on the " Geology of the Ocean Floor " at the British Museum (Natural History).

Saturday, 19th March.—A party of 38 members visited the Walton Works of the Metropolitan Water Board.

Thursday, 14th April, to Tuesday, 19th April (Easter).—Mr. P. J. Channon conducted a party, varying in strength from 15 to 27, to many fossiliferous localities in the Cotswolds near Cheltenham.

Saturday, 23rd April.—Mr. T. Eastwood demonstrated the geology of the Nuneaton district to a party of 30, which included members from both the Midlands and North Staffordshire Groups.

Sunday, 1st May.—Under the leadership of Mr. R. J. Schaffer a party of 32 spent an interesting, though somewhat unorthodox, day examining the Stones of London's Buildings.

Saturday, 7th May.—Mr. P. Evans demonstrated certain features of the Central Chilterns to a party of 29.

Saturday, 14th May.—Professor H. L. Hawkins conducted a party of 32 to Bucklebury, Boxford and Newbury.

Saturday, 21st May.—A party of 28 members and friends collected from the fossiliferous beds of Barton and Milford-on-Sea under the leadership of Messrs. E. St. John Burton and D. Curry.

Saturday, 28th May.—Dr. J. F. Kirkaldy demonstrated solution phenomena around Water End, North Mimms to a party of 27.

Friday, 3rd June, to Monday, 6th June (Whitsun).—Under the leadership of Dr. R. W. Pocock a party which reached a maximum strength of 37 paid an enjoyable and instructive visit to the Woolhope Dome.

Saturday, 11th June.—Mr. B. W. Sparks lead a party of 30 members and friends to study the geomorphology of the South Downs in the neighbourhood of Bramber and Findon.

Sunday, 19th June.—A coach trip under the direction of Mr. W. S. Pitcher enabled comparative studies to be made of the Lower

London Tertiaries of the Upnor, Herne Bay and Pegwell Bay sections. Twenty-four members attended.

Saturday, 25th June.—Mr. F. J. Epps led a party of 30 to view once again the classic sections in the Lower London Tertiaries at Charlton, Plumstead and Lessness Abbey, Abbey Wood.

Friday, 1st July, to Sunday, 3rd July (Week-end).—Under the leadership of Mr. D. F. W. Baden-Powell, 14 members attended a meeting to study the Lowestoft District.

Saturday, 9th July.—Mr. W. H. E. Rivett conducted a party of 25 to study Geology applied to Land Drainage and sources of Water Supply in Surrey.

Saturday, 16th July.—Mr. I. E. Higginbottom led a party of 13 on a strenuous meeting starting at Lewes and finishing at Newhaven.

Saturday, 23rd July.—A party of 20, accompanied Mr. R. Casey to collect from the basal Gault and Fokestone Sands at Farnham and Wrecclesham.

Saturday, 30th July, to Thursday, 11th August (Summer).—The Summer Meeting was divided into two sections. From 30th July till 7th August, Dr. R. G. S. Hudson and Dr. W. W. Black led a party, which reached a maximum strength of 46, to study the Lower Carboniferous beds around Malham. The majority of the party stayed at the Malham Tarn Field Centre. The examination of higher Carboniferous horizons was then continued, using Chesterfield as centre. Dr. G. W. Himus led the party over the Ashover Dome, Mr. S. Strawbridge demonstrated open cast sites and Mr. T. M. W. Strong, of the Anglo-Iranian Oil Co., welcomed the party to the Eakring Oilfield. Fourteen members attended the Chesterfield portion of the Field Meeting.

Saturday, 13th August.—Dr. T. Barnard conducted a party of 24 on a motor tour to study the Stratigraphy, Structure and Geomorphology of south-west Surrey.

Saturday, 27th August.—An experiment, an afternoon walk through London to trace the course of two buried rivers, proved successful, 20 members taking part under the leadership of Dr. J. F. Hayward.

Saturday, 17th September.—Mr. S. W. Hester demonstrated sections in the Harefield neighbourhood to a party of 18.

Saturday, 24th September.—Messrs. A. G. and R. J. Bell led a party of 36 to study the geology of the Eynesford neighbourhood in Kent.

Sunday, 1st October.—Twenty-eight members accompanied Dr. A. J. Bull and Mr. G. S. Sweeting in a Traverse of the Cretaceous rocks around Westerham, Sevenoaks, Tonbridge and Tunbridge Wells.

Saturday, 12th November.—A party of 24 spent an interesting afternoon at the Southall works of Messrs. Le Grand, Sutcliff and Gell. About 25 members applied too late for places.

Saturday, 10th December.—Professor H. L. Hawkins and staff demonstrated the collections of the Geology Department at Reading University to a party of 30.

NORTH-EAST LANCASHIRE GROUP

The following Meetings and Field Meetings were held :—

25th March.—Lecture, " The Carboniferous of Dovedale," by Dr. D. Parkinson, F.G.S., F.Inst.P.

29th April.—Lecture, " Some Fossil Cryptograms," by Dr. A. Allsopp, M.Sc.

13th May.—Field Meeting : The Z-C_2 Limestones of Clitheroe. Leader, S. Westhead.

10th June.—Field Meeting : The River Loud and its Valley. Leader, J. Ranson, A.M.I.Min.E., F.G.S.

2nd July.—Field Meeting : The Millstone Grit Succession of Salmesbury. Leader, D. H. Learoyd, B.Sc., F.G.S.

28th October.—Annual General Meeting. Lecture, " The Role of Silica in the Igneous Rocks," by D. H. Learoyd, B.Sc., F.G.S.

25th November.—Annual Address, " The Geology of Ribblesdale," by J. Ranson, A.M.I.Min.E., F.G.S.

16th December.—Lecture, " The Igneous Rocks," by D. H. Learoyd, B.Sc., F.G.S.

MIDLAND GROUP

The following Meetings and Field Meetings were held during 1949 :—

22nd January.—Lecture, " Precious and ornamental stones," by A. J. Aiers.

5th March.—Lecture, " The preparation of material for microscopical examination," by E. D. Lacy, B.Sc., F.G.S.

29th April to 1st May.—Field Meeting : Shelve Area, Shropshire. Leaders, H. B. Whittington and H. Sanders.

11th June.—Field Meeting : South Lickey Hills. Leaders, W. G. Hardie and G. T. Warwick.

17th September.—Field Meeting : Sutton Park. Leader, A. Ludford, M.Sc., F.G.S.

24th September.—Field Meeting: Leek, N. Staffs. Leader, J. C. Parrack, B.Sc., F.R.G.S.

29th October.—Lecture, "Some aspects of water-supply and geology," by A. L. Lyon, M.Eng., M.Inst.C.E., M.Inst.W.E., F.G.S.

19th November.—Lecture, "The work of the soil chemist with special reference to the connection with geology," by G. H. A. Edwards.

10th December.—Exhibition of lantern slides, by Professor Shotton, Dr. Raw and Messrs. Bray, Hardie, Lyon and Parrack.

NORTH STAFFORDSHIRE GROUP

The following Meetings and Field Meetings were held :—

24th February.—Lecture with film, "Water Supply of North Staffordshire," by C. V. Brown, Engineer and Manager, Staffordshire Potteries Water Board.

3rd July.—Field Meeting: Manifold Valley. Leader, J. E. Prentice, Ph.D., F.G.S.

16th July.—Field Meeting: Etruria. Leader, J. Myers, B.Sc.

13th October.—(a) Exhibition of specimen; (b) Talk on Geological Photographs by the Chairman.

10th November.—Lecture, "The Mersey Tunnel," by W. Wilcox.

8th December.—Lecture, "Development in the Study of the North Staffordshire Coalfields," by F. Wolverson Cope, D.Sc., F.G.S.

DONATIONS TO THE LIBRARY DURING 1949

(*The donors are the authors of the works presented, except where otherwise stated*)

ARGENTINE, MUSEO DE CIENCIAS NATURALES "BERNARDINO RIVADAVIA."—Geological publications, Nos. 1 and 2 (1948–9).

BALLAST, SAND AND ALLIED TRADES ASSOCIATION.—"Sand and Gravel" (1948).

BROWN, E. E. S.—"Work for Amateur Geologists" (1949).

BUTLER, A. J.—"International Geological Congress. 18th Session, Great Britain, 1948" (1949).

CASIMIR, M.—"Dyke Phenomena of the Dicq Rock, Jersey," by M. Casimir and F. A. Henson, and eight other pamphlets.

CASTELLANOS, A.—"Sedimentos Neogenos del S.W. del Uruguay" (1948).

DACK, W.—"The Structure of the Eastern Part of the Lake District," by J. F. N. Green, and six other pamphlets.

Davis, A. G.—" Note on Captain Brown's Illustrations of the Conchology of Great Britain and Ireland, 1827 " (1949).

Éditions Delmas, Bordeaux.—" Études sur la formation du sol de la Gascogne " (1948).

Edmonds, J. M.—" Types and Figured Specimens of Lower Palaeozoic Trilobites in the University Museum, Oxford " (1949).

Fairbridge, R. W.—" Notes on the Geomorphology of the Pelsart Group " (1948) and two other pamphlets.

Geological Survey of Great Britain.—Maps, 1-inch Sheets 3, 5, 9, 12, 14–17, 53 (Scotland). " A Prospector's Handbook to Radioactive Mineral Deposits " (1949). " Petrology of the Northampton Sand Ironstone Formation," by J. H. Taylor (1949). Memoir, " Geology of the Northern Pennine Orefield. Vol. I. Tyne to Stainmore " (1948). War-time Pamphlets, Nos. 1, 4 (Pts. 1–6), 6 Supp. ii, 7, 8 (Pts. 3, 4), 9, 12 (Pts. 1, 2), 13 (Areas 1–8), 14, 15 (Pts. 1–8), 16, 17 (Pt. 3), 18 (Pt. 3), 20 (Pts. 1–10), 21–26, 27 (Areas 1, 2), 30, 31, 32 (Pts. 2, 3), 33, 34 (Pts. 1, 2), 35, 36 (Pts. 1, 2), 37, 38, 39 (Pt. 2), 40–47.

Green, J. F. N.—" The Breccia of Redcliff, Wareham " (1949).

Hallimond, A. F. and Butler, A. J.—" Magnetic Survey in Teesdale " (1949).

Hayward, J. F.—" Geochronology and Biological Change " (1949).

Jackson, J. W.—" Progress in Carboniferous Geology. The Millstone Grit Series " (1948).

New Zealand, Geological Survey.—" Outline of the Geology of New Zealand " and 22 pamphlets and reprints.

Portugal, Serviços Geológicos.—" Flora Mesozóica Portuguesa " (1948).

Pulfrey, W.—" The Nature and Origin of a Soapstone from near Kisii " (1946).

Quebec, Université Laval.—" La Conservation des Types Spécifiques à l'Université Laval," by R. Bureau (1948). " Cent Ans de Géologie au Canada," by P. L. G. Morin (1943). " Middle Cambrian Trilobites from the Conglomerates of Quebec," by F. Rasetti (1948).

Robinson, A. H. W.—" Deep Clefts in the Inner Sound of Raasay," and six other pamphlets.

Shotton, F. W.—" Graig Lwyd Axes from the Coventry Neighbourhood," (1949).

Wales, National Museum of.—" The River Scenery at the Head of the Vale of Neath " (1949).

OBITUARY NOTICES, 1949

FREDERICK NOEL ASHCROFT who died suddenly at the age of 70 was educated at Rugby School and Magdalen College, Oxford. At Oxford under Sir Henry Miers he acquired an interest in minerals which directed much of his life's work. He became a great collector, and made visits to Switzerland, where with his own hands he unearthed many important specimens. The large collection which he built up is now housed in the British Museum (Natural History), where it is accompanied by a series of photographs showing exactly the positions of the finds in the Swiss Alps. These photographs illustrate the thoroughness of all his work, for they are as far as possible printed in platinotype, in order that the record may be a permanent one. His hobby brought him into contact with mineralogists of many countries, and he collaborated with the Swiss mineralogists in the production of *Die Mineralien der Schweizeralpen*, which is illustrated with some of his photographs. He became President of the Mineralogical Society in 1942.

He was a trained accountant, and it is for his work as a treasurer and his advice on financial matters that British geology owes him a deep debt of gratitude. He was Treasurer of the Mineralogical Society for nearly 20 years before he became President ; and the Geological Society of London was fortunate to have him as its Treasurer for 18 years. While he did not appear much at meetings of the Geologists' Association, he had on many occasions given that body sound advice and guidance ; its system of trusteeship is due to him. Perhaps his greatest work in this field was his treasurership of the International Geological Congress of 1948 ; this extended over three years and was only finished a few weeks before his death. He will be remembered by many as a kindly and helpful friend.

[A.J.B.]

EDMUND JOHNSTON GARWOOD, F.R.S., died on 12th June, 1949. The Association has lost a member of over half-a-century's standing.

Born at Bridlington in 1864, the son of the Rev. William Garwood, he and his sister were adopted in infancy by their maternal uncle, Mr. John Williamson, of South Shields, owing to their mother's death. Mr. Williamson owned a villa overlooking Lake Como, to which he took the children every year, so travel became a lifelong habit. Garwood spent his second birthday at Naples, and at the age of seven he was in Paris immediately after the suppression of the Commune, which had involved the death of 35,000 people in street-fighting or by execution without trial. His nurse took him to the Morgue to see the unidentified corpses, and he ever after retained a vivid recollection of the terrible scene. He was educated partly by private tutors, partly at schools at Wiesbaden and Brighton, at Eton, and at Trinity College, Cambridge, where he studied geology under Prof. T. McKenny Hughes and Dr. John E. Marr, who became his lifelong friend.

In his youth he was a keen sportsman. He started alpine climbing at the age of 14, he was a skilled skater and played ice-hockey, he was a " wet bob " at Eton and he stroked the third Trinity boat. He played tennis and golf, he rode a " penny farthing " bicycle and later an ancient motor-cycle, which he named " Dorcas," because it was " full of good works " (Acts ix, 36). He was a skilful photographer, starting with the wet-plate process, he made many beautiful studies of mountain scenery, and he was the first to take three-colour microphotographs of rock-sections. He exhibited photographs at the Exhibition of the Photographic Society, in Calcutta, at the Alpine Club and at the Anglo-Japanese Exhibition.

After four years in business Garwood was able in 1891 to accept a Cambridge University Extension Lectureship in Geology and to join the teaching-staff of the Army Class at Harrow School. His interest in Lower Carboniferous stratigraphy arose out of work he began at this time for the County History of Northumberland, and which was to continue till the last volume appeared in 1940. He was already well known as an alpinist, and he accompanied Sir Martin Conway's two expeditions to Spitsbergen in 1896 and 1897. In 1899 he explored with Douglas Freshfield the Sikkim Himalayas around Kanchenjunga.

In 1901 he was appointed to the Yates-Goldsmid Chair of Geology at University College, in succession to T. G. Bonney. The chair was a part-time one, the salary small, there was no departmental grant, and the department was housed in one room on the top floor of the College. He threw himself with energy and enthusiasm into the work of building up the department, in which he was ably seconded by Miss E. Goodyear, who was appointed his assistant in 1903. He was the first teacher at University College to use a projection lantern, which he bought out of his own pocket, with slides that he made himself, as he had no technician. By 1907 the Geology Department under his tutelage had grown to such an extent that it had to be moved to much larger quarters, and our members were invited to come and inspect it on 12th June, 1908.

For Garwood was an active member of the Association, to which he had been elected in 1896, and as our headquarters were at University College he naturally became more closely associated with us after his appointment to the chair. In 1903 he was elected to the Council, and in the following year he became our Honorary Librarian. At that time our books were housed in St. Martin's Public Library, but they were beginning to outgrow the accommodation allotted to them, and an increasing number of books and unbound journals, for which there was no room on the shelves, were stored inaccessibly at Gower Street. The Library was little used by our members, but it involved the Association in considerable expense for binding and upkeep, and an honorarium had to be paid to the librarian of St. Martin's. Our new Honorary Librarian, having a foot in two camps, was able to resolve the difficulty. At his suggestion the Association offered the Library as a free gift to University College on condition that our members had access in perpetuity to the whole of the College Science Library, the College authorities undertaking to maintain the Association's Library in an efficient condition at their own expense. The offer was accepted, it relieved the Association of a heavy financial burden, and it has proved of lasting benefit to both Association and College.

Garwood always maintained his close interest in the Association. He remained Librarian for 12 years. During his tenure of the chair our members thrice visited the Geology Department at University College (1908, 1916, 1927). He exhibited at our conversazioni, showing his coloured microphotographs of rock-sections, his ingenious sounding-machine for use on mountain lakes without a boat, sections of corals and of the calcareous algae which he had made his special study. His extensive field-work in mountainous and glaciated regions had led him to the view that ice has a protective as well as an erosive function, and this view he expounded to our members in a number of lectures on rock-basins, mountain-tarns and other features of Alpine and Himalayan scenery. He wrote the chapter on Northumberland and Durham for our Jubilee volume. He contributed an important paper on the Faunal Succession in the Lower Carboniferous Rocks of Westmorland and North Lancashire to our *Proceedings*, and in 1916 led the Long Excursion to the Shap-Ravenstonedale district. His last paper, a note on the organs of reproduction in *Solenopora gracilis*, appeared in our *Proceedings* as recently as 1945.

Garwood remained Yates-Goldsmid Professor till 1931. His duties included the teaching of Physical Geography and he did much to develop the Geography Diploma and, after 1918, the Honours Degree in Geography. He was an assiduous field-worker, patient and persevering, but his output of published work, though considerable, was less than it might have been, owing to his dislike of appearing in print until he had reached fully matured conclusions. He was accorded many honours, the Fellowship of the Royal Society, the Lyell Medal of the Geological Society, the Presidency of the Geological Society, of the Yorkshire Geological Society and of Section C of the British Association, and honorary doctorates of Leeds and Sheffield. He numbered many brilliant people among his friends, Lady Oxford and Asquith, Mme Tetrazzini, Elgar, Tosti, Kipling, F. W. Bourdillon, who had been his tutor, Sir Squire and Lady Bancroft, Owen Seaman, W. P. Ker, C. Whibley, and many others.

A few will remember Professor Garwood as an active member of our Council ; a few will remember him as an ever helpful senior colleague in College and University ; but many, who began their student days intending to specialise in some other subject, will remember the Professor who, by his inspiring lectures, his beautiful and fascinating lantern-slides, by his spirit of enthusiasm and the comradeship of his field-classes, first led them to abandon the paths in which their feet were set, and to pursue the way of Geology to the end. We have lost a friend, but we retain rich memories.

[L.J.C.]

John Frederick Norman Green, B.A. passed away on the 11th December, 1949, at Bournemouth, at the age of 76. Educated at Bradfield College where he was a Foundation Scholar, he entered Emmanuel College, Cambridge, in 1891 ; here he was a Mathematical Scholar, 1891, and a Boyd Scholar, 1891–4. He was bracketed 15th Wrangler in the Mathematics Tripos 1894, and in 1895 he obtained a 1st Class in Part II of the Natural Science Tripos.

After this brilliant university career he was appointed to H.M. Colonial Office in 1896, and in 1920 he became an Assistant Secretary. He retired in 1933. Among his many official activities he served as the Colonial Office representative on the Board of Governors of the Imperial College of Science and in a similar capacity on the Board of Governors of the Imperial Institute.

Apart from his official duties he found time for geological studies, and he has left a long and most impressive series of researches. His earliest published work (1908) was on the St. David's area of Wales. He then turned to the Lake District and later to the Scottish Highlands. It was after his retirement that he became interested in the problem of river denudation particularly in south-east England.

Green joined the Association 1904, and was President 1918-20. He was elected an Honorary Member in 1940. He became a Fellow of the Geological Society in 1908, and the value of his researches was recognised by the award of the Lyell Medal in 1925, then in 1934 he became President. His two Presidential Addresses reflect the breadth of his interests ; one was on the Moine Complex and the other on the rivers of southern England.

In 1912 he published the first of a series of papers on the structures of the Lake District, shown by his own mapping and that of other workers. During the succeeding eight years he continued this work, and concluded that previous estimates of the thickness of the Borrowdale Volcanic Series had been too great, that the apparent thickness was due to intricate folding, and that almost all the rhyolites belonged to one horizon near the top of the Series. Later work by others along the southern margin of the Series has confirmed these conclusions.

It was due to his friend George Barrow, the Highland geologist, that Green was stimulated to become interested in the Dalradian and Moinian rocks of the north. To these he devoted his spare time over a number of years and contributed to the *Quarterly Journal of the Geological Society* two papers, one on Islay (1924) and the other on the Highlands from Islay to Loch Leven (1931) ; there followed his first Presidential Address.

Green was one of the founders of the Weald Research Committee and for many years took an active and inspiring part in its activities. His first personal work in the Weald was on the River Mole (1934), of which he made a measured profile ; however, when it came to the publication of this work he insisted on the inclusion of a number of other names. It was characteristic of him that he should want to include everyone who had helped, however little that help might have been.

On retirement he went to live at Bournemouth, with the result that the centre of gravity of river work in this country shifted to the west. All his work in the Weald has not been published, he worked on other rivers than the Mole, and carried out some mapping of the northern outcrop of the Weald Clay. From Bournemouth there came a series of papers published by the Association, all of which have an important bearing on the denudation problems of the Weald. " The High Platforms of East Devon " (1941) is a study of erosion levels which may have their counterparts in the Weald. Then followed the " Age of the Raised Beaches of South Britain " (1943) and the " Terraces of Bournemouth, Hants." (1946). The last mentioned paper was the result of careful mapping extending over a number of years ; it provided a reference set of terraces from the " Sicilian " downwards, several of which were related to their appropriate sea-levels, and in the Muscliff Delta he gave a demonstration of a still stand of sea-level at 24 feet O.D. In this and in the succeeding paper, " Some Gravels and Gravel Pits in Hampshire and Dorset " (1947), Green developed some ideas regarding bluff deposits, which the writer thinks will have an important bearing on Pleistocene problems. His last paper published only last year was " The History of the River Dart, Devon." By his death geology has lost an inspiring and original worker, and many geologists a kindly and helpful friend.

[A.J.B.]

MRS. R. S. HERRIES, whose death is announced, frequently accompanied her husband, President of the Association 1906–8, on excursions ; she will be remembered with deep appreciation by those who knew her. She took much interest in her husband's beneficient support of the Association, which she joined in 1902.

WILLIAM FRASER HUME, a member of the Geologists' Association since 1893, died on 23rd February, 1949, at his home in Rustington, Sussex. He was born in Cheltenham on 1st October, 1867, but the first eleven years of his life were spent in Russia where he acquired a good knowledge of French, German and Russian. After a couple of years at school in England he was sent to Collège Galliard, Lausanne, and then to Germany, so that he was a good linguist before he entered the Royal College of Science, London, in 1884. He took the Associateship of the Royal College of Science in Geology in 1889 and the Associateship of the Royal School of Mines in Metallurgy in the same year. He graduated at London University with first place in the B.Sc. Honours examination and was awarded the D.Sc. in 1893.

He was appointed on the staff of the Geological Department of the Royal College of Science, London, in 1890, was Senior Demonstrator in 1897 and was Examiner in Geology to the Royal Indian Engineering College, Cooper's Hill. He also lectured on geology to the students of the School of Engineering (now the Faculty of Engineering, Fuad I University, Cairo) for a number of years from 1907 onwards.

Hume joined the Geological Survey of Egypt in 1897, one year after it had been founded by Capt. Lyons (later Col. Sir Henry Lyons, F.R.S.). In 1909 Col. Lyons, then Director-General, Survey Department and Director, Geological Survey, resigned and Hume succeeded him as Director, Geological Survey.

The Geological Survey of Egypt was founded to undertake a geological reconnaissance of the country and in the beginning its work included both geographical and geological exploration. For the first 25 years the expeditions had to rely on camel transport and in the early days only the minimum amount of equipment and transport was available, so work was often carried out under extremely trying and uncomfortable conditions.

The reconnaissance maps were on small scales (1 : 500,000 and 1 : 250,000), but areas were mapped on 1 : 100,000 and 1 : 50,000 in districts where the expeditions had discovered mineral deposits. These discoveries led directly to the foundation of the important phosphate and manganese mining industries and the geological exploration was of great value in the search for petroleum. Hume discovered the "oil-rock" at Hurghada in 1911, two years before the Anglo-Egyptian Oilfields drilled their first successful oil-well.

From the earliest days of the Geological Survey some members of the staff were engaged on measuring river discharges in the Sudan and on the examination and mapping of the cataracts of the Nile to determine the most suitable sites for reservoirs. Between 1901 and 1907 Hume spent five field-seasons on this work.

Hume was adviser on water-supply to the British Army in Egypt, 1915–17, and in connection with the advance through Northern Sinai he paid frequent visits to the front. He summarised the results of his investigations for publication in the *British Army Medical History of the War.*

During the 1914–18 war the Egyptian Government decided to intensify the search for oil in Egypt and a Petroleum Development Committee was formed with Hume as a member. He was in charge of the geological investigations until the Government decided to close down the work in 1924. The results of the field-work were published between 1920 and 1925 in 12 " Petroleum Research Bulletins."

One of Hume's earliest publications appeared in the *Proceedings* of the Geologists' Association, 1895. It was a joint paper with Prof. T. McKenny Hughes and Horace W. Monckton, entitled " Notes of a Geological Excursion in Switzerland," and described some geological phenomena observed on the excursions of the International Geological Congress, Zurich, in 1894.

Hume attended many International Congresses where his gift of languages and fluent speaking were an immense advantage. He attended the International Geological Congress at Zurich in 1894 and that held in Russia in 1897. As Director of the Geological Survey of Egypt he was a delegate of the Egyptian Government to a number of congresses. He was sent to Stockholm to the International Geological Congress and the Agrogeological (Soils) Congress which were held there simultaneously in 1918, and was elected a Vice-President of both congresses. He attended the International Geological Congress in Canada in 1913 and the International Geographical Congresses that were held at Cairo, 1925 ; Cambridge, 1928 ; Paris, 1931 ; and Amsterdam, 1938.

Hume had published seven papers before he went to Egypt, three of these being on Russian geology. His publications number more than 100, 20 of them being joint papers. Hume's first publication for the Geological Survey was a joint report with Barron, on the work of their two parties during two seasons in the desert. It was entitled *Topography and Geology of the Eastern Desert of Egypt* (*Central Portion*) and appeared in 1902. It included a geological map on 1 : 500,000, and laid down the main lines of the topography and geology of an area of about 30,000 square kilometres. This was followed by *The Topography and Geology of the Peninsula of Sinai* (*South-eastern Portion*), 1906, which deals with about 3,750 square kilometres of some of the most rugged country on the surface of the earth, consisting of confused hill masses of igneous and metamorphic rocks, cut by deep ravines, of which a number are " rift " valleys.

In 1912 he produced a new geological map of Egypt, scale 1 : 1,000,000, which embodied much labour and was a notable advance on existing maps.

His greatest work is *The Geology of Egypt* in three volumes divided into six parts.

Volume I, which deals with the surface features of Egypt was published in 1925.

Volume II, is on the Fundamental Pre-Cambrian Rocks of Egypt. Part I, *The Metamorphic Rocks*, appeared in 1934. Part II, *The Later Plutonic and Minor Intrusive Rocks*, in 1935. Part III, *The Minerals of Economic Importance* associated with the Pre-Cambrian, in 1937.

Volume III, Part I, deals with *The Older Sedimentary Rocks from the Close of the Pre-Cambrian Episodes to the end of the Cretaceous Period.*

Part II, *The Tertiary to Recent.*

The text of this volume was completed in 1945, but the preparation of the plates and figures was seriously retarded by Hume's absence from Egypt during the war, and it needs some re-arrangement and much work on the illustrations before it will be ready for the press.

These volumes contain a comprehensive account of the geology of Egypt, derived from Hume's wide knowledge and experience of Egyptian geology and his careful study of the work of others in the voluminous literature relating thereto. They illustrate the great advance that has been made since he joined the Geological Survey.

In 1927 he relinquished the post of Director and was made Technical Counsellor, Geological Survey, in order that he could devote his whole time to writing his *Geology of Egypt*.

After 1927 he went to Egypt, at first for six months and later four months each year and worked for the rest of the time in England where he could discuss problems that arose in his work with specialists and consult publications that were unobtainable in Egypt.

He was decorated with the Order of Ismail, Second Class, in 1938, having previously received the Order of the Nile both Third Class and Second Class.

Hume was elected a member of the Council of the Royal Geographical Society of Egypt in 1917, and in 1926 His Majesty King Fuad I appointed him President of the Society. He held this office until 1940 when he was unable to return to Egypt owing to the war. He was President of the Institut d'Egypte in 1928 and Vice-President for 11 years between 1913 and 1932. He was a Fellow of the Royal Society of Edinburgh, Fellow of the Royal Geographical Society, and President of the Littlehampton Natural Science and Archaeological Society.

Hume's linguistic abilities coupled with a naturally amiable manner gained for him many friends of different nationalities, while his kindly and charitable nature endeared him to all with whom he came in contact, and his loss will be deeply felt.

[O.H.L.]

GUY NEVILLE EAGLESTONE KENNETT-BARRINGTON, M.A., F.R.G.S., M.R.I., of The Manor House, Dorchester-on-Thames, who died on 31st March, 1949, aged 65, was the only son of the late Sir Vincent Kennett-Barrington, whom he succeeded as Lord of the Manor of Dorchester, and was educated at Badley's School and Magdalen College, Cambridge. He will be remembered by some of the older members as a frequent attendant of meetings and excursions of the Association, which he joined in 1912. During his membership he accumulated a considerable collection of rocks and minerals. His chief interest lay in local government and, during the two great wars, he did much useful work in a voluntary capacity.

[A.G.B.]

PHILIP LAKE died on 12th June, 1949, at the age of 84 years. After taking his degree at Cambridge in 1887 he was appointed to the Geological Survey of India, but resigned three years later and returned to Cambridge where he lived until his death. He became Reader and Head of the Department of Geography. For his work on Trilobites and on the Lower Palaeozoic formations of North Wales Lake was awarded the Lyell Medal in 1912. His chief palaeontological work is *A Monograph of British Cambrian Trilobites* (*Palaeont. Soc.*, London, 1906–46). His other writings include a theory of *Mountain and Island Arcs* and a critical examination of Wegener's theory of continental drift. Of Lake's *Physical Geography*, first published in 1915, 45,000 copies have been printed, and a revised edition will appear shortly. With R. H. Rastall he wrote the well known *Textbook of Geology*.

Lake will be remembered by his pupils as an excellent teacher, and by his friends as a man of wide learning and sound judgment.

[H.W.]

SIDNEY HUGH REYNOLDS, M.A., Sc.D. (Cantab.) died at Clifton, Bristol, on 20th August, 1949, at the age of 81. The Geologists' Association has lost a member of many years' standing and a staunch supporter of its aims and activities.

Educated at Marlborough College and Trinity College, Cambridge, of which University he held the degrees of M.A. and Sc.D., he early came under the influence of T. McKenny Hughes and J. E. Marr.

In 1894 he joined the staff of University College, Bristol, as lecturer in Geology and Zoology and was subsequently appointed Professor in the same subjects. This wide experience undoubtedly gave him the broad outlook of a naturalist and many members of the Association will recall the delightful way when professedly discussing geology in the field, he would stop and refer to a plant or a bird or some other natural history phenomenon which attracted his attention. The University of Bristol was founded in 1909 and Reynolds became the first occupant of the Chaning Wills Chair of Geology—a position which he held until his retirement in 1933. Thus for nearly 40 years Reynolds influenced a succession of students all of whom would wish to pay tribute to his kindly, just nature, his modesty, and his unfailing patience even in the days of limited staff.

During the whole of this long period his publications bear witness to accurate field work and intensive study in the laboratory. His early work with C. I. Gardiner was in Western Ireland, but as his students increased in numbers he concentrated on the Bristol District, especially on the Silurian rocks of Eastern Mendip and Tortworth, and the Avonian of several areas. The results of his deliberations on the Carboniferous Limestone of England and Wales were summarised in a presidential address to Section C of the British Association in 1926. Pleistocene mammalia and latterly the relationship of surface scenery to the underlying rocks also engaged his attention.

He was elected a Fellow of the Geological Society in 1891 and was awarded the Lyell Fund in 1904 ; in 1928 the Society recognised his work with the award of the Lyell Medal.

He joined the Geologists' Association in 1901 and contributed many papers to its *Proceedings*. Mention may be made of his paper on the Lower Palaeozoic rocks of Gloucestershire and Somerset in the Jubilee Volume in 1910. On several occasions he conducted members of the Association around the Bristol District and contributed several papers describing the geology of the areas visited.

Local and visiting students will always be grateful to Professor Reynolds for his useful geological guide to the Bristol District first published in 1912.

It is impossible to include in a short obituary mention of every activity in a life so devoted to science and his students. Many remember his gracious presence, appreciative comments and kindly acts, and consider it a privilege that they were allowed to be associated with him. He leaves a widow and daughter.

[F.S.W.]

THOMAS FRANKLIN SIBLY, who died on 13th April, 1948, had been a member of the Association since 1908. Most of his active work as a geologist was carried out before the early 1920's, but he retained a very keen interest in the subject and did a great deal in many ways to promote geological activities.

Sibly was born in Bristol in 1883 and graduated with a London degree from University College, Bristol, in 1903. His main subject was physics, but he became attracted by geology partly under the influence of S. H. Reynolds and Arthur Vaughan. As a result of association with the latter he began the study of the zonal sequence of the Carboniferous Limestone, and during the next 20 years he published a succession of most important papers on the sequence in areas ranging from Somerset and South Wales to Derbyshire. He devoted considerable attention to the structure of the Forest of Dean, and during the first war to the study of the iron ores associated with the limestones. The results of the latter investigation were published in a memoir of the Geological Survey and his last contribution to the geology of the Forest of Dean area, written jointly with S. H. Reynolds, was published in 1937.

He held Chairs of Geology in Cardiff and at Armstrong College, Newcastle-on-Tyne, but in 1920 became Principal of the newly-established University College of Swansea. From that time most of his energies were devoted to administrative work. At Swansea he inspired a small group of University teachers, and set the new college firmly on its feet as an academic institution of repute. He left Swansea to become the Principal of the University of London in 1926, but after a period of ill-health he accepted the less strenuous duties of Vice-Chancellor of the University of Reading, where he remained until his retirement a short time before his death.

Sibly acted in 1920 as one of the leaders of the Association's Easter excursion to the Cardiff district, and similarly in 1923 as a joint leader of the excursion to the Swansea district. He served for 13 years as Chairman of the Geological Survey Board, and in many other ways took part in Government activities related to the advancement of science. He was knighted in 1938 and made a K.B.E. in 1943. He received several honorary degrees from British universities. He will be remembered by many geologists, both amateur and professional, for his clear mind, his kindly good humour and for the ready assistance which he gave to all engaged on geological work. He is survived by Lady Sibly and his only son, Mr. T. Sibly.

[A.E.T.]

EDWARD W. TUNBRIDGE was by profession a lawyer, having passed his Law Final examination when he was 22, with the award of the Birmingham Law Society's Bronze Medal and the Law Society's Prize ; but before this he had graduated at Birmingham University with Honours in Mechanical Engineering. A life-long interest in Geology was roused by contact with Professor Charles Lapworth. His special study was petrology, which he pursued in the field both at home and abroad, devoting to it most of his holidays and a good deal of his leisure. He died suddenly on 11th October, 1948.

[L.J.W.]

THE CHRONOLOGY OF THE DEGLACIATION OF SCOTLAND

By A. D. LACAILLE, F.S.A.

[*Received 7th October*, 1946]

CONTENTS

	PAGE
INTRODUCTION	121
THE CLIMATIC SEQUENCE	121
THE FORESTS	122
STRATIGRAPHY	126
THE FAUNA	133
ACKNOWLEDGMENTS	141
REFERENCES	141

SUMMARY.—The climatic changes, floral and faunal developments attending the deglaciation of Scotland are considered. The pollen-analysis of peats reveals a forest history and sequence in this country very similar to those in the Baltic area. It confirms and amplifies the deductions drawn from the observations of deposits in sections. These, exposed in the greater Scottish estuaries, in lake-beds and upland mosses, show clearly the succession from Late-Glacial times to Recent.

INTRODUCTION

As far back as last century Scottish geologists concluded from their studies of peat layers and forest beds that the climate did not recover in a regular manner after the deglaciation of their country. It has, however, been left to Scandinavian scientists to exploit the discovery that by counting pollen grains, particularly of forest trees, preserved in peat, a more accurate picture of these changes is obtained. Their linking of the botanical, zoological and archaeological findings with the geochronological scale based on varved clays gives a fairly complete history of the Late-Glacial and Early Post-Glacial periods.

Such pollen-analyses as have been carried out in Scotland tell little of the earlier passage from arctic conditions but prove more informative about the later. That country, however, affords unrivalled scope for the application of these critical methods which have thrown so much light on Post-Glacial climatic changes in the Baltic region. It is confidently expected therefore that when investigations are extended in Scotland the pollen sequence will be narrowed into zones as in Denmark and parts of England and Ireland.

THE CLIMATIC SEQUENCE

The climatic succession in Scotland from the Late-Glacial period onward corresponds to that established in the Baltic area.

There is evidence in northern Europe [**1***; **2**] to show that climatic fluctuations followed the Late-Glacial severities. They were: (1) a sub-arctic phase, the *Early* or *Lower Dryas Period* when tundra conditions prevailed; (2) a phase of amelioration, the Allerød Oscillation belonging to the end of the Götiglacial Period of retreat, allowing of the growth of willow, birch and some pine; (3) a sub-arctic phase, the *Late* or *Upper Dryas Period* marked by a flora similar to, but rather more abundant than that of the Early Dryas Period, indicating a temporary return to cold. It probably synchronised with the halt of the ice along the line of the Fenno-Scandian End-Moraine. A like sequence is represented in Ireland [**3**] and England [**4**].

After the second spell of sub-arctic conditions the climate improved under a rising temperature until optimum was reached in the Early Post-Glacial period. This phase of transition, the *Pre-Boreal*, was marked by an increasing vegetation. On both sides of the North Sea the Post-Glacial climate comprises four phases representing a twice repeated cycle of dry and wet conditions, beginning with the oldest: (1) *Boreal*, dry continental climate; (2) *Atlantic*, warm, moist insular climate; (3) *Sub-Boreal*, renewed continental climate; (4) *Sub-Atlantic*, return to damp, colder climate.

Figs. 1, 2 and 3, having reference to Scotland, show two methods of illustrating the results of pollen-analysis. Hazel (*Corylus*), reckoned separately, is expressed as a percentage of the total tree pollen present.

THE FORESTS

(*a*) The Pre-Boreal climatic phase (*circa* 7800–6800 B.C.) covered the Finiglacial Period of retreat in the Baltic area. It witnessed the early coming of willow (*Salix*), the maximum growth of birch (*Betula*), the gradual rise of pine (*Pinus*) and the introduction of aspen (*Populus tremula* Linn.) and hazel. The phase coincided at first with the Yoldia Sea and later with the uplift of the land whereby the Ancylus Lake was enclosed. It was marked by similar floral developments in the British Isles whilst the remnant ice melted away and the land rose gradually. By the end of this phase connections existed between Britain and the Continent. The Late Pre-Boreal or Early Boreal age of the peat, or moorlog, from the Dogger Bank and other shoals, which prove the reality of the emergence, is indicated by pollen-analysis [**5**, 677–8; **6**, 340]. That the deposit was formed in a freshwater fen away from the sea is shown by its contained plant and beetle remains [**7**, 41–73].

(*b*) The beginning of the succeeding Boreal climatic phase (*circa* 6800–5000 B.C.) synchronised with the opening of Post-Glacial time in northern Europe. The phase, marked by a rapidly

---

* For list of References see p. 141.

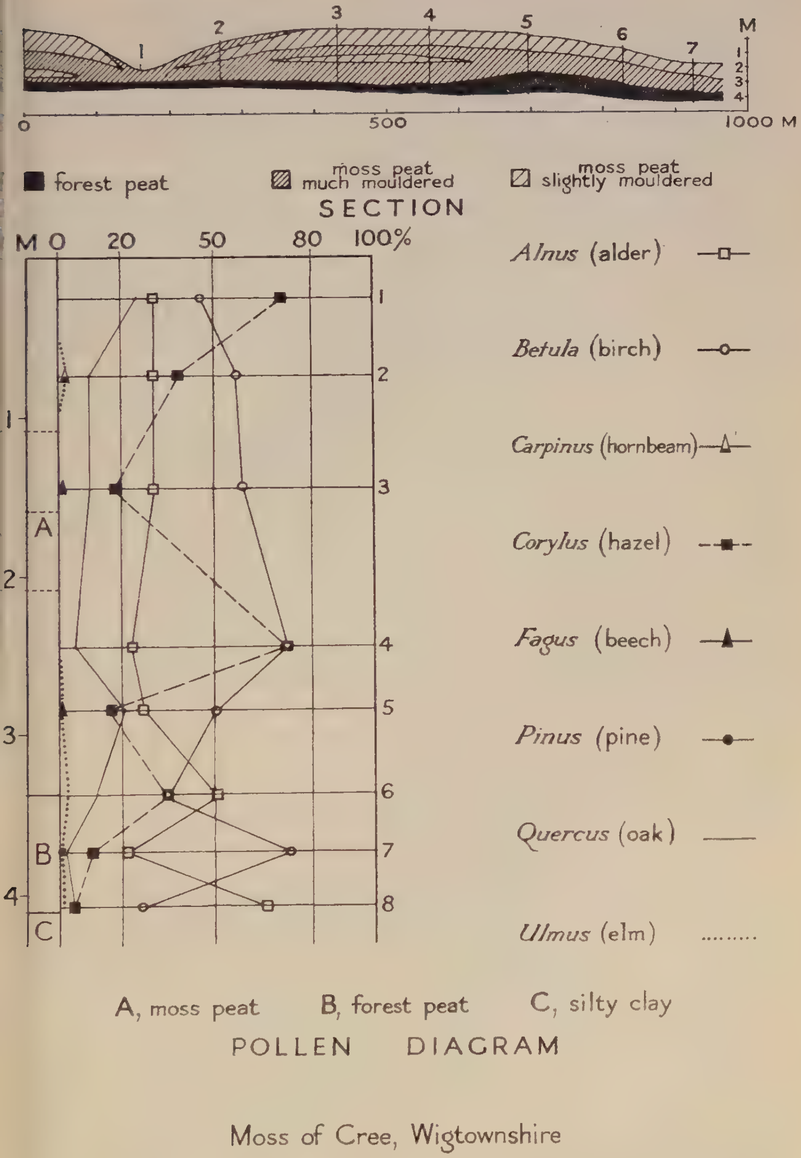


FIG. 3.—POLLEN-ANALYSES OF PEAT SAMPLES FROM THE BEDS OVERLYING THE EARLY POST-GLACIAL RAISED BEACH AT MOSS OF CREE (SOLWAY FIRTH), WIGTOWNSHIRE. The peat samples analysed are numbered 1 to 8 downward. The percentages of tree pollen at different depths are marked off on the horizontal line.

(Redrawn from Erdtman.)

rising temperature, was contemporary with the main development of the Ancylus Lake, and therefore with the maximum emergence of the sea-floors outside. Over an enlarged northern and north-western Europe dry continental conditions prevailed inducing the widespread growth of forests. Pine early became dominant in Denmark ; later such deciduous trees as oak (*Quercus*), elm (*Ulmus*) and lime (*Tilia*) appeared. Hazel attained its maximum, flourishing at heights and latitudes where it is no longer found. The British Isles and locally their extended coastal grounds became clad with forests. In Scotland these at first consisted mainly of birch and pine, to which were added later a dense undergrowth of hazel, some alder (*Alnus*), oak and elm. At least one fourth of the country became wooded even to altitudes and in regions now treeless, notably in the west and north, the Hebrides, Orkneys and Shetlands. Changing conditions later in the Boreal phase led to the formation of peat at aquatic sites in Scotland [**8**, 17–18].

It was towards the end of this phase that the land-bridge between Sweden and Denmark was broken and the Litorina Sea came into being. About the same time the submergence of the connections between the Continent and Britain began, and the drowning was initiated of the tracts upraised around these islands during the preceding climatic phase.

A dug-out canoe of pine has been reported from Friarton, Perth, in the Tay basin, lying under the carse clay and upon the peat layer, a former land surface crowded with roots [**9**, 391–2. Fig. 5, iii and iii a]. This is of Boreal age [**10**, 181–2]. Several such boats are recorded also from the estuarine deposits, of the Forth below Stirling and of the Clyde in and near Glasgow [**11**, 66–7, 70–3]. It seems improbable, however, that any of these vessels dates back so far, though some may possibly belong to the succeeding Atlantic climatic phase when the lower reaches of the Tay, Forth and Clyde were considerably distended.

(*c*) The Atlantic climatic phase (*circa* 5000–2500 B.C.) coincided with the occupation of the Baltic basin by the Litorina Sea and with the equivalent transgression of the reclaimed sea-floors and coastal grounds of north-western Europe. During the first half of the phase the Post-Glacial climatic optimum was attained. It synchronised with the maximum of the high-level seas.

Under marine influence the moist conditions combined with the warmth to encourage the spread of deciduous trees. Save in the highest and northernmost parts of Scandinavia a mixed forest replaced pine. Its most important constituents were oak and elm with the later introduction of maple (*Acer*) and lime. There were similar developments in the British Isles where pine died out in many parts. At first the Mixed-Oak-Forest (*Quercetum mixtum*), which included alder, hazel and birch, made some progress in Scotland. But in this comparatively small country surrounded by an enlarged sea, the conditions of the Atlantic phase proved detrimental to its increase. Excessive winds and rains initiated the deforestation of the mainland and adjacent islands, and induced the rapid formation of peat-mosses. In fact the climate so deteriorated in the Shetlands at least that arctic-alpine plants grew down to sea-level ; these islands have since been treeless. Locally it brought about increased precipitation at high altitudes giving rise to conditions akin to glacial [**12**, 11].

(*d*) The Sub-Boreal climatic phase (*circa* 2500–850 B.C.) witnessed the progress of land recovery begun during the preceding phase. Under its cooler and drier conditions the Mixed-Oak Forest decreased and pine attained a second maximum in Scandinavia. Hornbeam (*Carpinus*) and beech (*Fagus*) appeared there later. In many regions the new forest became established on the compact layer (the *Grenzhorizont* of the Baltic lands) formed by the drying and hardening of the surface of the Atlantic peat. In others the equivalent formation supported only grasses and heath, particularly in Scotland, where moors developed rather than woods. Nevertheless, a mixed forest again spread on the mainland, where some trees grew to 3200 feet above present sea-level [**8**, 16]. In it birch and alder were fairly abundant, but not elm. Oak did not establish itself generally though actually more frequent than the pine of the higher grounds. Beech appeared as the climate altered towards the end of the Sub-Boreal phase. To this can be assigned most of the tree remains found in inland lakes and bared in rent and wasted peat-hags (Fig. 4).

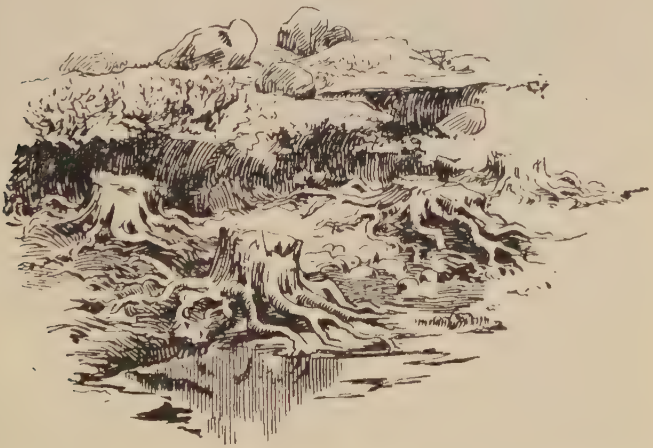


FIG. 4.—TREE ROOTS IN THE PEAT ON RANNOCH MOOR.

(*By permission L.N.E.R. Co.*)

The drier and cooler conditions of the Sub-Boreal climatic phase induced the heaping of wind-blown sand locally upon the hardened Atlantic layer, also round and upon rocks studding the Early Post-Glacial raised beach. Great archaeological interest attaches to many of the sand-dune areas, especially along the mouth of estuaries (*e.g.* Fig. 5, iv).

(*e*) The Sub-Atlantic phase, opening about 850 B.C. with a rapid change to cold and wet, carries the history of our climate to the present time. The decreasing warmth, damp and oceanic conditions, characterising it from the start, have affected continental Europe less than Scandinavia and the more northerly and westerly parts of the British Isles. The phase has been marked throughout by the immense development of *Sphagnum* peat at the expense of forests in these regions.

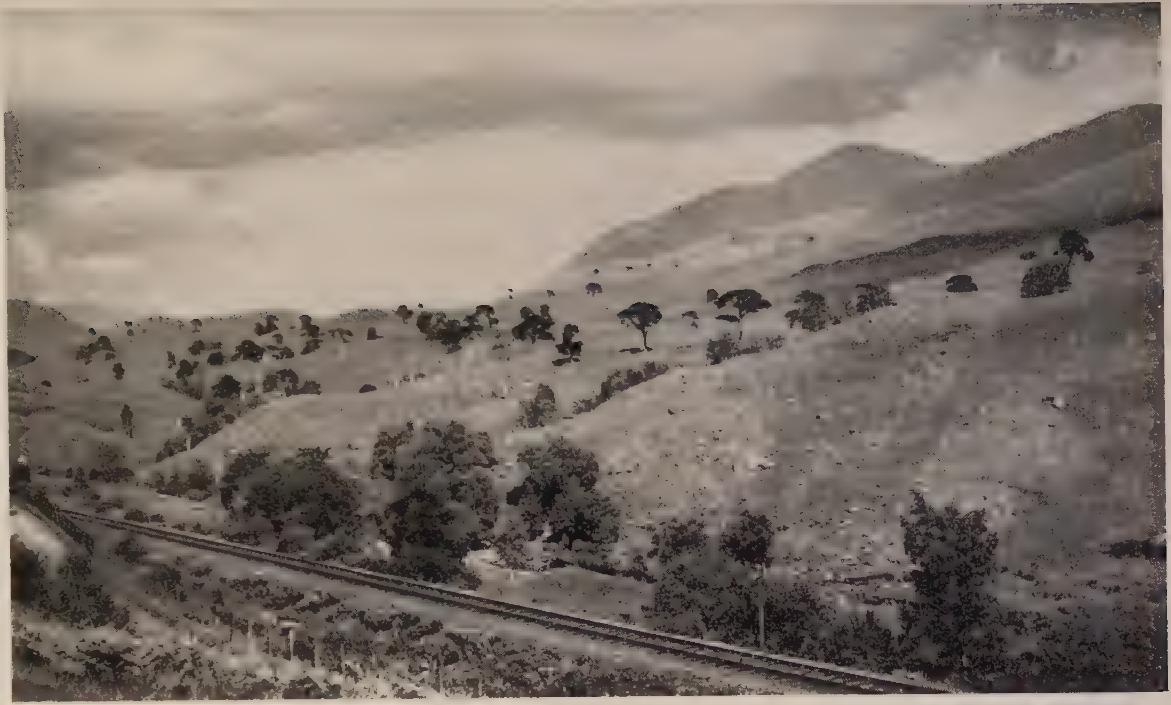
To hornbeam, which spread early in Sub-Atlantic times, spruce (*Abies*) was added among the trees of Scandinavia, but the separation of Britain from the Continent prevented any extensive natural invasion of conifers. That conditions in Scotland since the beginning of this phase have been unfavourable also to the diffusion of broad-leaved trees is shown by the feeble pollen content of the upper peat layers.

(*f*) To the climatic conditions responsible for the denudation of the woodlands man has from the beginning of historic times given his destructive aid, so effectually indeed that in Scotland the very term *forest* has come to be used restrictively and to denote the usually quite treeless and infertile sporting-ground of the deer-stalker. Yet, self-grown alders, birches, hazels and small oaks today cover parts of the Southern Uplands. Together with rowans they clothe Highland straths and sheltered loch-banks, dot the slopes of glens and fringe the narrow hill burns. In the Outer Hebrides and on the rocky western mainland a few puny birches, dwarfed hazels and stunted rowans cling in crannies ; sallows grow on damp grounds in the West Highlands ; and native pines, these " Scots Firs " (*Pinus sylvestris* Linn.), which one always intimately connects with the idea of Scotland, here and there rear their gnarled and twisted trunks in some open, rocky and formerly heavily glaciated regions in and beyond the Grampians (Plate 4). These living reminders of the vanished forests of Scotland are quite distinct from the modern plantations.

STRATIGRAPHY

(a) Nature of Deposits

Deposits clearly demonstrating the sequence from Ice Age conditions to Sub-Atlantic in Scotland have been revealed in estuaries, along the coasts, and inland in peat-mosses and lake sites. Various Late-Glacial sediments rest upon the ground-moraine and



(*Photo. by J. Michieli, London.*)

VIEW IN GLEN FALLOCH, PERTHSHIRE: Ben More (3.843 ft.) in background ; relics of the deglaciation and native pines in centre ; self-grown alders, birches, hazels and oaks fringeing stream in foreground.

[*To face p.* 126.

are overlain by Post-Glacial beds. The presence or absence of one or other layer is of local significance only.

(b) The Estuaries

Some of the classic sketches of sections in the estuaries of the Clyde, Forth, Tay and Ythan [**13**, 183–94 ; **14**, 290–2] are reproduced with recent drawings and interpretations (Figs. 5–9).

The Late-Glacial deposits consist of clays, muds and stratified sands and gravels laid down by the cold high-level sea. Here and there they are crumpled and contorted, presumably by the stranding of ice-rafts [**14**, 271–3], and contain great stones, some covered with barnacles (*Balani*), which were carried by floating ice. Up-valley they pass into the river terraces. Upon them rest the Post-Glacial beds whose age has been determined by pollen-analysis.

The first important Post-Glacial bed is a tightly compressed peat containing remains of hazel, willow, birch, pine, oak and elm. The pollen-analysis of samples from Ochtertyre Moss in the Forth Valley, above Stirling, and Forgandenny in the lower Tay basin, south of Perth, indicates that it is of full Boreal age [**10**, 181–3]. Since the peat-bed passes beneath present sea-level, it is part of the land surface which, being elevated after the transgression of the Late-Glacial sea, extended our coasts and united Britain to the Continent. It is the equivalent, therefore, of the late Pre-Boreal–Early Boreal moorlog of the Dogger Bank and other shoals now under the waters of the North Sea (p. 122, above). But the land surface in the northern peripheral region was submerged after the central and more southerly parts of the sea-floors. This discrepancy, permitting the immigration of a number of warmth-loving trees, explains the later pollen-spectrum for the shallow marginal peat-beds of Scotland and of north-western Germany [**15**, 36–7].

The Boreal layer can be correlated with the submerged Early Post-Glacial forests and peat-beds exposed at points on the coasts of England, Wales and Ireland, and with vestiges of vegetation between tide-marks and under sands at several places on the shores of Scotland, Orkneys, Hebrides and Isle of Man [**14**, 290–3 ; **7**, *passim*]. They point to a lesser depression in certain regions than others.

Stoneless silty clay of varying thickness rests upon the Boreal peat in many estuaries. It was laid down during the transgression of the Early Post-Glacial sea which followed the emergence of the land. So far the carse-clay has not yielded pollen, but other indicators show that the temperature rose and the climate improved during the main period of its deposition (p. 136, below). It can be confidently assumed that this took place during the Atlantic phase, for the estuarine clays overlying the Boreal layer are capped by peat

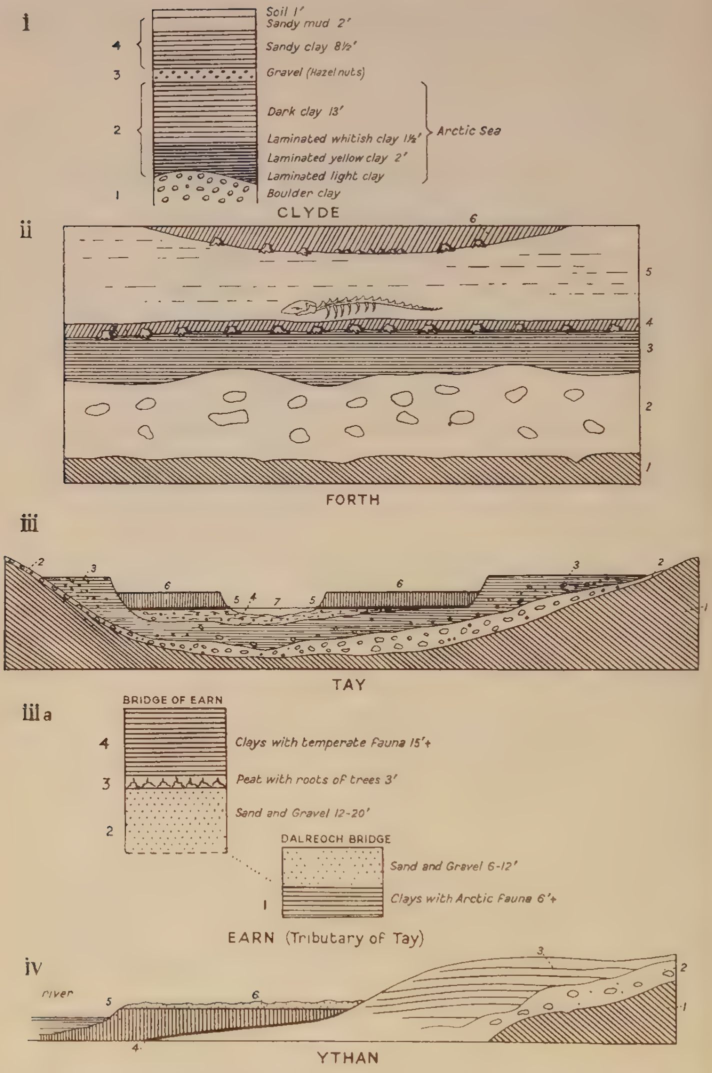


FIG. 5.—SECTIONS IN THE ESTUARIES OF CLYDE, FORTH, TAY AND YTHAN.

KEY to Figs. 5–9.

A Last glaciation.
B Period of submergence and transgression of the Late-Glacial sea.
C Period of emergence ; Boreal age.
D Period of submergence and transgression of the Early Post-Glacial sea ; Atlantic age.

E Emergence ; Sub-Boreal age.
F Sub-Atlantic age.

i—Clyde : Abbey Mills, Paisley, Renfrewshire.

(*By courtesy of Dr. M. Macgregor.*)

	Deposit	*Interpretation*
4.	Sandy clay and sandy mud	*D*
3.	Gravel (hazel nuts)	*C*
2.	Clays, arctic sea	*B*
1.	Boulder clay	*A*

ii—Forth : Blair Drummond Moss, Perthshire (p. 130).

(*Redrawn from Jamieson.*)

	Deposit	*Interpretation*
6.	Peat with remains of old wooden road and stools of oak in lower part	*E and F*
5.	Carse-clay with bones of whale	*D*
4.	Peat with remains of trees	*C*
3.	Late-Glacial marine beds	*B*
2.	Boulder clay	*A*
1.	Bed-rock (sandstone)	

iii—Tay : Carse of Gowrie, Perthshire.

(*Redrawn from J. Geikie.*)

	Deposit	*Interpretation*
7.	Recent alluvia	
6.	Carse-clay containing animal bones	*D*
5.	Peat with hazel nuts and remains of trees	*C*
4.	River sand and gravel	(*passage from B to C*)
3.	Marine clays, " 100-ft. terrace "	*B*
2.	Boulder clay	*A*
1.	Bed-rock	

iii a—Earn (tributary of Tay): Bridge of Earn and Dalreoch Bridge, Perthshire (p. 124).

(*By courtesy of Dr. M. Macgregor.*)

	Deposit	*Interpretation*
4.	Clays with temperate fauna	*D*
3.	Peat with roots of trees	*C*
2.	Sand and gravel	(*passage from B to C*)
1.	Clays with arctic fauna	*B*

iv—Ythan : Aberdeenshire (pp. 126–7).

(*Redrawn from Jamieson.*)

	Deposit	*Interpretation*
6.	Blown sand, etc. (added)	*E and F*
5.	Estuarine mud with shells	*D*
4.	Peat	*C*
3.	Stratified clay and sand, or glacial-marine beds	*B*
2.	Boulder earth or glacier-mud	*A*
1.	Bed-rock (gneiss)	

determined by pollen-analysis to be of Sub-Boreal–Sub-Atlantic age, as in the basins of the lower Tay and Forth (*supra*, p. 124).

Besides the canoes from the estuarine deposits in the lower reaches of Tay, Forth and Clyde mentioned above (p. 124), a human dolicocephalic skull, of undetermined age, has been discovered at 21 feet from the surface at Grangemouth, Stirlingshire [**9**, 402]. Other relics of man from deep down in clays around Stirling can, however, be placed in the archaeological sequence. The most remarkable are implements made in antler of red deer.

West of Stirling, in the extensive Kincardine Moss, the lower part of the Sub-Boreal–Sub-Atlantic peat contains tree-stools, including those of oak, rooted in the subjacent clay. Here a bronze cauldron of Late Bronze Age–Hallstatt (Early Iron Age) type [**12**, 158–9] was found beneath the upper peat. The same formation in Blair Drummond Moss, nearer Stirling (Fig. 5, ii), has yielded a wooden mortar [**16**, 34], and has been observed to entomb rooted trunks bearing axe-marks, and to overlie a roadway of felled logs [**17**, 426].

(c) The Age of the Early Post-Glacial Raised Beach

Few openings have been made in the Scottish Early Post-Glacial raised beach. Nevertheless, its contained fossils and its relation to other deposits show that this formation of gravels and sands is of the same age as the estuarine clays. Peat has been found under the beach at Machrihanish, Kintyre (Argyll), but its pollen-statistics are as yet unpublished [**18**, 62]. Containing fragments of rank underwood and hazel-nuts (Fig. 6), it has been noted beneath the beach gravels in the Firth of Clyde at Rothesay, Isle of Bute [**19**, 320–3]. The peat-bed at these places is the counterpart of that under the equivalent raised beach in Northern Ireland, which, being assignable to the Late Boreal–Early Atlantic transition, is a portion of the ancient land surface reclaimed from the sea during the emergence.

At the head of many estuaries peat spreads over the Early Post-Glacial raised beach or its equivalents. Locally two layers have been distinguished, and the pollen of samples from Wigtownshire (Fig. 3) and Dumfriesshire has been analysed. The lower, much mouldered and containing remains of trees, gives a Sub-Boreal reading, the upper, a *Sphagnum* formation, only slightly altered, a Sub-Atlantic spectrum [**10**, 173–6]. At several points on the coast, including Shewalton Moor, Ayrshire, an accumulation of peat has been observed resting on sand on top of the beach proper. In Ardgour and Lochaber this peat[1] is formed of moorland plants, and the underlying sand contains drifted pieces of oak without roots [**20**, 813–15].

From the above it appears that in Scotland, as in Northern Ireland, the making of the raised beach, like the laying down of the estuarine clays, probably extended into the Late Atlantic climatic phase. Unfortunately, these deposits of such importance by their

---

[1] It is interesting to find in these localities that an identical and presumably contemporary peat rests upon the remains of trees, including oak, rooted in the "50-foot" beach which registers a stage in the fall of the Late-Glacial sea.

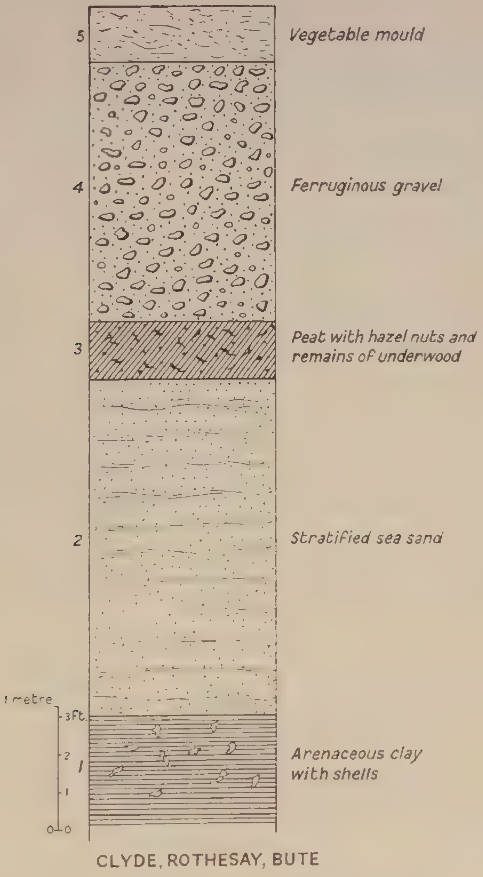


FIG. 6.—SECTION AT ROTHESAY, BUTE.

(Based on Miller's description.)

5. Vegetable soil.
4. Ferruginous gravel ; raised beach recording the transgression of the Early Post-Glacial sea, Atlantic age (*D*).
3. Peat with hazel nuts and remains of underwood ; attributable to period of emergence, Boreal age (*C*).
2. Stratified sea sand } attributable to the Late-Glacial sea (*B*).
1. Arenaceous clay with shells }

content of stone implements, which constitute the earliest indisputable record of man in Scotland, have not been studied as thoroughly as their Irish counterparts. Yet, even now it is satisfactory that independent deductions in Scotland so accord that, taken with the data from Ulster,[1] they afford bases for the correlation and comparison of the archaeological and allied evidences.

(d) Upland Peat-mosses

Pollen-analysis indicates that the climatic record enshrined in Scottish upland peat-mosses agrees with that established in the estuaries and on the seaboard [**10**, 177–81 and 183–7]. The most comprehensive sections have been recorded in the south (Fig. 7). Here sub-arctic, alpine and Pre-Boreal plant remains resting upon morainic materials denote the gradual passage from the last period of intense cold. Overlain by vestiges of the Boreal forest, they are in turn covered by peat which may be assigned partly to the Late Boreal but mainly to the moister conditions of the Atlantic climatic phase. Traces of a poor flora including tree-stools rooted in the Atlantic layer betoken the renewal of forest growth during the Sub-Boreal phase. The whole is sealed by peat, Sub-Boreal in its lower part and Sub-Atlantic in the upper. In the north of Scotland generally, and in all the islands, the Boreal forest only is represented, and the heavy overburden of peat is extremely poor in pollen (*supra*, p. 126).

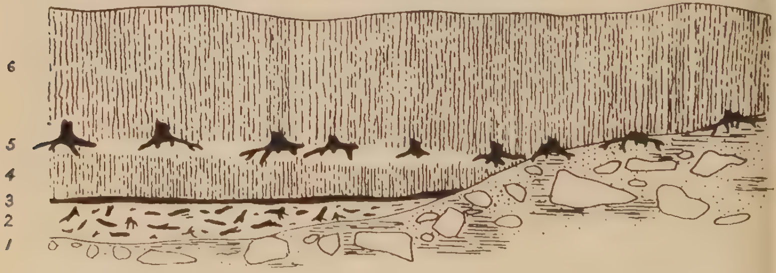


FIG. 7.—SECTION IN THE MERRICK-KELLS MOSSES, KIRKCUDBRIGHTSHIRE.

(*After Lewis. With permission of Royal Society of Edinburgh.*)

6. " Recent peat," Sub-Boreal (*E*) in lower part, Sub-Atlantic (*F*) in upper.
5. " Upper Forest," pine ; Sub-Boreal (*E*).
4. Eriophorum peat. } Atlantic (*D*).
3. " Second or upper Arctic bed," sphagnum peat } Atlantic (*D*).
2. " Lower Forest," willow in the lower part, birch in the upper ; passage from Sub-Arctic to Boreal (*B—C*).
1. Morainic material ; last glaciation (*A*).

---

[1] This is due in the first place to the detailed geological and faunal studies of coastal deposits by Dr. R. Ll. Praeger, who established the Post-Glacial stratigraphy in Northern Ireland [**21** ; **22** ; **23**].

(e) Peat-filled Lakes

The climatic sequence from Ice Age to Post-Glacial is fairly displayed in peat-filled lakes. In the Midland Valley, particularly in Angus, these have long been known to afford the most complete record. They entomb intercalated marls or detritus-beds which have yielded mammalian remains, vestiges of plants including trees, and clays. Recently the critical methods of pollen-analysis have been used to determine the age of the different sediments [**10**, 183]. Samples from White Loch Moss near Dunning, Perthshire, indicate that the detritus-bed, in which birch is dominant, is of Boreal age and rests upon a Pre-Boreal layer. At Loch Kinnordy, Angus, the equivalent bed of marl, underlying what is probably an Atlantic–Sub-Boreal detritus-bed, is believed by analogy with Irish marls to be of pre-Atlantic age. A section noted long ago in Whitrig Bog, Berwickshire [**24**, 297–9], a favoured locality even early during the retreat of the New Drift ice [**25**, 49–50], revealed a series of deposits similar to that entombed in some Irish bogs [**26** ; **27**].

An attempt is made in Table I to interpret our pioneer investigators' principal deductions in the terms of climatic phases based on pollen-analysis, and with the approximate dates of the geochronological (varve) scale.[1] Table II shows how the climatic developments are believed to have synchronised with the late periods of the deglaciation and the attendant ice-movements.

THE FAUNA

(a) Marine Molluscs

Molluscs abounded on the shores of the Late-Glacial sea during its decline, and in the more southerly areas of its transgression. *Chlamys* (*Pecten*) *islandicus* Müller, *Astarte compressa* Montg. and *Tellina* (*Macoma*) *calcarea* Chem. [**35**, 82] are among the many characteristic forms identified in the clays and muds laid down by the high-level sea. They have been reported from the lower reaches of the larger rivers and from points along the east coast from Peterhead to the Firth of Forth [**13**, 181 ff.]. Around Paisley and Glasgow the deeper water deposits of the cold sea have yielded great numbers. Many are recorded from equivalent beds farther down the Firth of Clyde [**19**, 320–3, and pp. 130–1, above], and elsewhere in the central western kyles and sea-lochs as far north as Benderloch, Argyll [**36**, 369]. An exposure in Bute, at Kilchattan Bay (Fig. 8), deserves special mention [**13**, 173–4]. It revealed a shell-bed under the well-developed Early Post-Glacial raised beach. The fossiliferous stratum, though containing forms more northern than those which today inhabit the shores of Bute, seems to be referable to the time

---

[1] An interesting study of the bottom deposits of Windermere [28], having special reference to the diatom succession, has revealed a climatic record of sedimentation undisturbed by sub-aerial erosion and agreeing with the order as set forth above. Close research on the same lines in the open glacial lakes of Scotland would doubtless prove as illuminating.

TABLE I

A TERMINOLOGY OF LEWIS [20; 29; 30; 31]	B EPOCHS OF J. GEIKIE [32, 278–81]		C CLIMATIC PHASES Erdtman [10] Sernander [33]	D GEOCHRONOLOGY Approx. years B.C. De Geer [34]
Recent peat	Recent and Present		Sub-Atlantic	850
Forest	Upper Forestian		Sub-Boreal	2500
Peat bog plants with Arctic plants				
Forest				
Peat bog plants	Upper Peat Bog	Lower Turbarian	Atlantic	5000
Arctic plant bed	Second Arctic Bed			
Peat bog plants	Lower Peat Bog			
Forest	Lower Forestian		Boreal	6800
Arctic plant bed	First Arctic Bed		Pre-Boreal	7800

TABLE II

Approx. years B.C.	BRITAIN		BALTIC		Climatic phases
	Retreat of the ice	Land and Sea	Retreat of the ice	Water Bodies	
	POST-GLACIAL	EMERGENCE Present Sea	POST-GLACIAL	BALTIC SEA	SUB-BOREAL
2500		SUBMERGENCE Drowning of land-connections ; Britain separated from the Continent ; transgression of the coasts of Scotland, etc. ; formation of raised beach up to nearly 50ft. above O.D. in Scotland		LITORINA SEA	ATLANTIC
5000		EMERGENCE Britain united to the Continent ; partial land-bridges between Britain and Ireland		ANCYLUS LAKE	BOREAL
6800					PRE-BOREAL
7300	THIRD PERIOD	SUBMERGENCE Late-Glacial sea recorded by strand-line, etc., up to about 155ft. above O.D. in Scotland	FINI-GLACIAL	YOLDIA SEA	
7800	SECOND PERIOD		GOTI-GLACIAL	ICE-DAMMED LAKE	

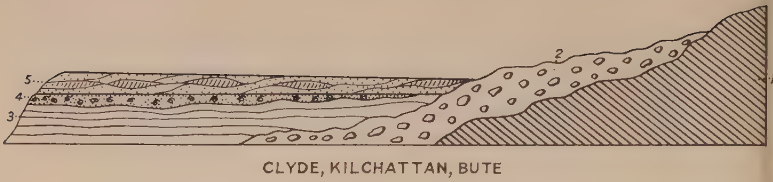


Fig. 8.—Section at Kilchattan, Bute.

(Redrawn from Jamieson.)

5. Gravel and shingle ; raised beach recording the transgression of the Early Post-Glacial sea (*D*).
4. Shell-bed ; recovery of the land well advanced (*B* passing to *C*).
3. Fine laminated clay ; Late-Glacial sea (*B*).
2. Boulder-earth ; last glaciation (*A*).
1. Bed-rock (sandstone).

when the land had risen well out of the Late-Glacial sea, the deposits of which it was observed to overlie. Clay beds and moraines contain specimens which supplement other proofs of the occupation of the Loch Lomond fjord by the Late-Glacial sea (p. 139, below).

As the temperature rose to the Post-Glacial optimum, so the more northern types of molluscs gave place to southern forms. The later groups are abundantly represented by fossils in the Scottish estuarine beds and raised beach deposits laid down during the Atlantic climatic phase. They are predominantly of molluscs still living on our shores, and typical of the assemblage after which the Litorina Sea in the Baltic trough has been named. Among them are to be counted the remains of such forms as *Scrobicularia piperata* Gmelin and *Cylichna obtusa* Montg. These have been recovered from as far north respectively as Loch Spynie, near Elgin, and the mouth of the Ythan, north of Aberdeen [**13**, 203]. After the climatic optimum some northern forms such as *Cyprina islandica* Linn. reappeared [**13**, 181].

(b) The Vertebrate Fauna

Remains of vertebrates from the deposits of the Late-Glacial sea are scanty but interesting, if only because they testify to the extent of the marine transgression. They have been found mainly in the basins of the greater estuaries, particularly the more southerly. In these areas the fossiliferous beds are certainly later than the last glacial episode in central Scotland, since locally they rest upon boulder clay (Fig. 9) and lap round kames and eskers [**14**, 273].

(i) *Fishes*

Fishes lived in the Late-Glacial sea, but owing to their perishable nature few fish-bones have been recovered. They have been recorded from Invernettie near Peterhead in the north-east [**37**, 518],

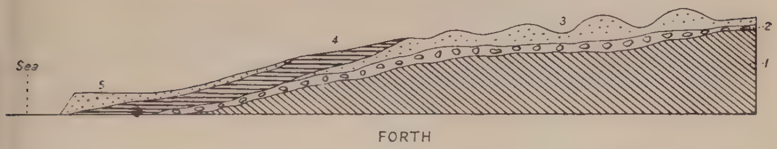


Fig. 9.—Section in the Forth Estuary, Showing the Relation of the Kames to the Underlying and Overlying Deposits.

(Redrawn from J. Geikie.)

5. Recent beach deposits ; attributable to the Early Post-Glacial sea (*D etc.*).
4. Brick-clay, etc. ; attributable to the Late-Glacial sea (*B*).
3. Kames series ; retreat of the ice.
2. Boulder clay ; last glaciation (*A*).
1. Bed-rock.

Renfrew, Paisley and Greenock in central Scotland [**38**, 332, 338 ; **39**, 41] and Kilchattan Bay, Bute, in the south-west [**40**, 131].

It is thought that some " white-fish " resembling species now migratory in Arctic regions tenanted the Loch Lomond and Loch Eck fjords, and gradually adapted themselves to freshwater habits as the uplift of the land and resulting restriction of outlets converted these arms of the Late-Glacial sea into lakes. They would be represented today by an aberrant member of the Salmonidae, the powan (*Coregonus clupeoides* Lacépède) of these two lochs. (*Cf.* the pollan of Lough Neagh and other Irish inland waters that had been invaded by the flows of the Late-Glacial sea.)

(ii) *Birds*

Evidences of bird life in Scotland between the New Drift glaciation and the Early Post-Glacial period are furnished by the deposits of the Late-Glacial sea. They consist of the furcula of a gull (diver) and other bird-bones from around Paisley [**41**, 14], bones from a brickclay-pit at Jordanhill, Glasgow [**42**, 244] and the skeleton of a duck from Torry on the Dee opposite Aberdeen [**37**, 510].

Being usually small, bird bones are generally as imperfectly preserved in land deposits as in marine, consequently their identification is somewhat uncertain. But the remains of Ptarmigan [*Lagopus mutus* (Montin.)] from the lower and upper layers in the caves at Inchnadamph, Sutherland, leave no room for doubt [**43**, 347]. This bird must have been an early forerunner of the abundant avifauna which reached Scotland and spread as the climate became milder.

(iii) *Marine Mammals*

Of the skeletal remains from the marine clays, those of the Arctic Seal (*Pagomys foetidus* Gray) clearly reflect conditions along the margins of the cold sea. They have been found on the east coast at several places, even quite distant from the present coast-line, from the lower Dee at Westfield of Auchmacoy near Aberdeen to Portobello in Midlothian [**44**]. The most outstanding come from Errol between Dundee and Perth in the Tay estuary ; Springfield, Fife, 10 miles up the Eden valley ; Tyrie, half a mile inland from Kinghorn, Fife ; Grangemouth and Camelon, Stirlingshire, the latter almost four miles from the nearest point on the Forth.

Bones point to the increase of marine mammals in the coastal seas of Scotland under the improving Early Post-Glacial climate. Many provide evidence of the considerable extent of the marine invasion which is correlated with the Litorina Sea of the Baltic region. The most remarkable, of whales found deep down in the carse-clay of the Forth, some with red deer antler artifacts, have been reported from Bridge of Allan [**45**] and Blair Drummond [**17**, 441]. At Campbeltown, Argyll, the deposits of the Early Post-Glacial raised beach have yielded remains of Grey Seal (*Halichoerus gryphus* Nilsson) [**46**, 272]. This species, Common Seal (*Phoca vitulina* Linn.) and Rorqual (*Balaena physalus* Linn.) are represented also in kitchen-middens resting upon this formation in islands in the same county.

(iv) *Land Mammals*

A few of the highest mountains in the south of Scotland may have reared their tops above the ice-sheets of the New Drift. Apart from this possibility there were no nunatak areas in Scotland. Hence it seems out of the question that any land animals, which had reached Scotland during the preceding period of climatic improvement, could there have survived the great readvance of the ice. It was otherwise in Ireland, the southern part of which was spared by the concomitant glaciation. Thither many members of the late Pleistocene fauna, which had spread widely in Ireland during the congenial spell before the New Drift, retreated and outlived the glaciation. Some forms, including the pachyderms, eventually died out in the refuge areas outside the limits of the New Drift and its associated advances in the British Isles. Again, some animals adapted themselves to the changing environment due to climatic improvement and vegetational development.

The indications of early mammalian northward migrations during the deglaciation of the British mainland are meagre indeed. So far nothing suggests that warm-blooded land forms returned to Scotland until the second period of retreat. The earliest records of the fauna after the New Drift glaciation are from the Victoria Cave, Settle, West Yorks. They consist of artifacts of Magdalenian type made in reindeer antler by man in the Creswellian (English Upper Palaeolithic) stage of cultural development [**47**, 120]. Cave-earth containing glacial erratics, carried presumably by a concomitant of the Scottish Readvance, in Dog Hole Cave, Warton Crag, near Carnforth, North Lancs., farther north-west, has yielded the bones of

Reindeer, Urus, Giant Deer, Common or Arctic Lemming, Northern and Siberian Voles [**48**]. These remains probably represent an extension of animal movements northward beyond Settle during the first period of retreat when plants grew in Cumberland [**49**, 244–5].

The land animals which reached Scotland as the climate improved are known from bones found in various deposits, mostly in the Midland Valley, and in caves in the Highlands, in marl, peat, ancient lakes and mosses, and in rivers. From the different circumstances of discovery, and variety of species represented, the exact order of distribution is not clear. This can be explained partly by the fact that the northern sea cut off the advance of the arctic and steppe animals and caused them to become mixed with forms which normally lived under different conditions [**50**, 12–13]. However difficult it may be, therefore, to demonstrate the sequence, it is certain that the mountainous north-west and west for long afforded habitats, or refuge-areas, appropriate to the last survivors of the arctic fauna.

It appears that a portion of antler found with marine shells in a glacial deposit at Croftamie, Dunbartonshire, near Drymen, [**51** ; **52**] can now be assigned to a phase of the second period of retreat which may have corresponded with the Allerød Oscillation in the Götiglacial Period in the Baltic area. It would point to the presence of the reindeer near Loch Lomond when it was an arm of the sea and inhabited by characteristic arctic molluscs before the readvance of the glacier down the fjord [**53**, 641–3]. By the time the ice had almost disappeared from the Midland Valley, about the end of the same period of retreat from the line or the Lammermuir-Stranraer Moraine [**54**, 110–13], a few hardy animals had reached the Forth basin. An important group from the Pentland Hills was found to include remains of Wolf, Horse and Reindeer. It has been referred to this stage of retreat [**14**, 304–5]. At Corstorphine, near Edinburgh, deposits overlain by the outwash gravels and sands of the melting Forth glacier in a silted-up glacial lake have yielded bones of the Giant Deer (*Megaceros hibernicus* Owen) and Arctic Lemming (*Dicrostonyx torquatus* Pall.), associated with the vestiges of plants still living within the Arctic Circle. These included Dwarf Birch (*Betula nana* Linn.), Willows (*Salix polaris* Linn., *S. herbacea* Linn., *S. reticulata* Linn.), White Dryas (*D. octopetala* Linn.), *Oxyria digyna* Hill and the phyllopod crustacean *Lepidurus* (=*Apus*) *glacialis* Krøyer [**43**, 342]. This assemblage indicates a climate earlier than Pre-Boreal, its species being identical with those which established themselves in the wake of the retreating ice while the Yoldia Sea still occupied the Baltic trough [**36**, 439].

To the east, at Portobello, the jawbone of a wolf was found in clay laid down by the Late-Glacial sea [**55**, 319], or in the same conditions as the remains of Arctic Seal (pp. 137–8, above). All these animal remains indicate that the stocking of Scotland began in

Late-Glacial times, and the character of the land forms represented betokens the resumption of the northward push of the fauna after being halted in the north of England by the Scottish Readvance, which episode closed the first period of retreat.

The Cave Bear (*Ursus spelaeus* Blum.) and such characteristic cold forms as Arctic Fox (*Canis lagopus* Linn.) and Northern Vole (*Arvicola* or *Microtus ratticeps* Keys and Blas.) are known only from the lower beds in caves in the valley of the Allt nan Uamh near Inchnadamph in Assynt. Their bones have been found in association with those of other hardy animals including Arctic Lemming. Since the last has also been recorded near Edinburgh, it is concluded that the arctic creatures represented in the north-west were early arrivals in the south of Scotland.

As the vegetation developed and forests spread under the rising temperature, so animals in increasing numbers gained Scotland from the south, some doubtless across the uplifted sea-floors and partial land-bridges. By its reduction of the estuaries and extension of the coastal grounds, the Early Post-Glacial emergence of the land would facilitate faunal migrations beyond Forth, to (and in) the west. Because of their interest, further attention may be paid to some of the members of the rich fauna which reached Scotland.

The Reindeer offers a remarkable picture of the adaptation of a form long inured to cold to the geographic, climatic and vegetational changes which succeeded the Ice Age in Scotland. As shown by the distribution of its remains, this animal found a congenial environment in the south and south-west and many parts of the North Sea basin as far as the Orkneys. It eventually developed into a woodland race, which probably long persisted, though it is quite unlikely that it endured until the twelfth century of this era as has been suggested. The Giant Deer, the largest of the early immigrants, did not become as common in Scotland as in Ireland. Apparently confined to the region south of Forth, it seems to have disappeared before the beginning of the Early Post-Glacial period. On the other hand, its forest congener, the Elk (*Alces machlis* Ogilby), roamed over the flatter parts from Wigtownshire to north Sutherland and endured longer. Its remains, like those of the Giant Deer, have been recorded mainly from marl-beds underlying peat, as at Whitrig Bog (p. 133, above). Among other cervids, the Red Deer (*Cervus elaphus* Linn.), a much larger creature than its protected descendant of restricted range, spread even to the Orkneys, Shetlands and Hebrides.

Cowdon Glen, Renfrewshire, is to be credited with the few bones of Wild Horse (*Equus caballus ferus* Nel.) found stratified in Scotland. Their Early Post-Glacial age is indicated by the character of the associated plants and animal remains [*cf.* J. Geikie, **44**, 162], among which those of another steppe form, the Great Ox or Urus (*Bos primigenius* Boj.), are outstanding. This beast, widely distributed over southern Scotland and in the plains of the North Sea basin as far as Caithness, declined from the time of the formation of the peat-mosses.

Of the larger beasts of prey, Wolf, one of the earliest arrivals, had the widest distribution and persisted longest. Until about the tenth century it was associated with Brown Bear (*Ursus arctos* Linn.) which it outlasted by several hundreds of years. The presence of another vanished carnivore is attested by the bones of Lynx (*Lynx lynx* Linn.), but only from an upper layer in a cave near Inchnadamph.

Great interest attaches to the Variable Hare (*Lepus variabilis scoticus* Newton) [**43**, 345], the remains of which are numerous in the Assynt caves. The colour-changes of this animal in autumn and spring recall its past associations, and indicate that this form ranks as an early immigrant.

Not long after the stocking of Scotland was completed during the Boreal climatic phase, there occurred the land-sinking and marine invasion which are correlated with the transgression of the Litorina and Tapes Seas. Since the mainland of Britain was thereby cut off from the Continent and its communications with Ireland and other islands were severed, further natural introductions were confined to the accidental dispersal of certain plants and birds.

(c) Man

As shown by artifacts from dated deposits, it was only towards the end of the Boreal and beginning of the subsequent climatic phase that man reached Scotland where he found game-abounding fens, hazel scrubs and developing forests, fish-stocked rivers and lakes, generous shores and coastal waters.

ACKNOWLEDGMENTS

In preparing this paper and its forerunner on the deglaciation of Scotland and attendant geographic changes [**56**] the writer has been indebted for help in various ways to Dr. R. G. Absalom, Newport, Mon. ; Dr. F. W. Anderson, Edinburgh ; Mr. D. Baden-Powell, Oxford ; the late Dr. A. J. Bull, London ; Professor J. K. Charlesworth, Belfast ; Dr. H. Godwin, Cambridge ; Dr. J. W. Jackson, Buxton ; the late Mr. A. S. Kennard, London ; Professor W. J. McCallien, Gold Coast ; Dr. M. Macgregor, Glasgow ; Dr. K. P. Oakley, London ; Dr. J. B. Simpson, Edinburgh ; and Mr. J. A. S. Stendall, Belfast. He wishes to record his gratitude to all.

REFERENCES

1. JESSEN, K. 1935. Archaeological Dating in the History of North Jutland's Vegetation. *Acta Archaeologia*, 5, pp. 185–214.
2. ———. 1938. Some West Baltic Pollen Diagrams. *Quartär*, 1, pp. 124–39.

3. Jessen, K. and Farrington, A. 1938. The Bogs at Ballybetagh, near Dublin, with Remarks on Late-Glacial conditions in Ireland. *Proc. Roy. Irish Acad.*, 64, B, 10, pp. 205–60.
4. Godwin, H. 1940. Pollen-Analysis and Forest History of England and Wales. *New Phytol.*, 34, pp. 370–400.
5. Erdtman, G. 1924. Studies in Micro-Palaeontology. II. Moorlog from the Dogger Bank. *Geol. Förens. Stock. Förh.*, 46, pp. 676–8.
6. Godwin, H. 1934. Pollen-analysis : an outline of the problems and potentialities of the method. *New Phytol.*, 33, pp. 278–305, 325–58.
7. Reid, C. 1913. *Submerged Forests.* Cambridge.
8. Fraser, G. K. 1943. Peat Deposits of Scotland. Pt. I. *Geol. Surv. Gt. Brit., Scotland.*
9. Geikie, J. 1881. *Prehistoric Europe.* London.
10. Erdtman, G. 1928. Studies in the Postarctic History of the Forests of Northwestern Europe. I. Investigations in the British Isles. *Geol. Förens. Stock. Förh.*, 50, pp. 123–92.
11. Munro, R. 1899. *Prehistoric Scotland.* London.
12. Childe, V. G. 1935. *The Prehistory of Scotland.* London.
13. Jamieson, T. F. 1865. On the History of the last Geological Changes in Scotland. *Quart. Journ. Geol. Soc.*, 21, pp. 161–203.
14. Geikie, J. 1894. *The Great Ice Age and its Relation to the Antiquity of Man.* Third Edition. London.
15. Clark, J. G. D. 1936. *The Mesolithic Settlement of Northern Europe.* Cambridge.
16. Wilson, D. 1851. *The Archaeology and Prehistoric Annals of Scotland.* Edinburgh.
17. Blackadder, A. 1824. On the Superficial Strata of the Forth District. *Mem. Wernerian Nat. Hist. Soc.*, 5, pp. 424–41.
18. McCallien, W. J. and Lacaille, A. D. 1941. The Campbeltown Raised Beach and its Contained Stone Industry. *Proc. Soc. Ant. Scot.*, 75, pp. 55–92.
19. Miller, H. 1863. *Sketch-book of Popular Geology.* Edinburgh.
20. Lewis, F. J. 1911. The Plant Remains in the Scottish Peat Mosses. Part 4. The Scottish Highlands and Shetland, with an Appendix on the Icelandic Peat Deposits. *Trans. Roy. Soc. Edin.*, 47, pp. 793–833.
21. Praeger, R. Ll. 1892. Report on the Estuarine Clays of the North-East of Ireland. *Proc. Roy. Irish Acad.*, 2, pp. 212–89.
22. ———. 1896. Report on the Raised Beaches of the North-East of Ireland with Special Reference to their Fauna. *Proc. Roy. Irish Acad.*, 4, pp. 30–54.
23. ———. 1896 (*a*). A Bibliography of Irish Glacial and Post-Glacial Geology. *Ann. Rep. and Proc. Belf. Nat. Field Club*, 4, pp. 239–316.
24. Smith, J. A. 1872. Notice of the Discovery of Remains of the Elk (*Cervus alces* Linn. ; *Alces machlis* Gray) in Berwickshire ; with notes on its occurrence in the British Isles, more particularly Scotland. *Proc. Soc. Ant. Scot.*, 9, pp. 297–350.
25. Charlesworth, J. K. 1926. The Readvance Marginal Kame-Moraine of the South of Scotland, and some later Stages of Retreat. *Trans. Roy. Soc. Edin.*, 55, pp. 25–50.
26. Mitchell, G. F. 1940. Studies in Irish Quaternary Deposits : Some Lacustrine Deposits near Dunshaughlin, County Meath. *Proc. Roy. Irish Acad.*, 46, B, 2, pp. 13–37.
27. ———. 1948. Late-Glacial Deposits in Berwickshire. *New Phytol.*, 67, pp. 262–4.
28. Pennington, W. (Mrs. T. G. Tutin). 1943. Lake Sediments : The Bottom Deposits of the north basin of Windermere, with special reference to the diatom succession. *New Phytol.*, 42, pp. 1–27.

29. Lewis, F. J. 1905. The Plant Remains in the Scottish Peat Mosses. Pt. 1. The Scottish Southern Uplands. *Trans. Roy. Soc. Edin.*, 41, pp. 699–723.

30. ———. 1906. The Plant Remains in the Scottish Peat Mosses. Pt. 2. The Scottish Highlands. *Trans. Roy. Soc. Edin.*, 45, pp. 335–60.

31. ———. 1907. The Plant Remains in the Scottish Peat Mosses. Pt. 3. The Scottish Highlands and the Shetland Islands. *Trans. Roy. Soc. Edin.*, 46, pp. 33–70.

32. Geikie, J. 1914. *The Antiquity of Man in Europe*. Edinburgh.

33. Sernander, R. 1908. On the evidences of Postglacial changes of climate, furnished by the peat-mosses of northern Europe. *Geol. Förens. Stock. Förh.*, 30, pp. 465–73.

34. De Geer, G. 1928. Geochronology based on Solar Radiation, and its Relation to Archaeology. *Antiquity*, 2, pp. 308–18.

35. MacGregor, M. and MacGregor, A. G. 1936. The Midland Valley of Scotland. *Brit. Reg. Geol.*

36. Wright, W. B. 1937. *The Quaternary Ice Age*. Second Edition. London·

37. Jamieson, T. F. 1858. On the Pleistocene Deposits of Aberdeenshire· *Quart. Journ. Geol. Soc.*, 14, pp. 509–32.

38. Crosskey, H. W. and Robertson, D. 1871. The Post-Tertiary Fossiliferous Beds of Scotland. *Trans. Geol. Soc. Glas.*, 3, pp. 321–41.

39. ——— ———. 1874. The Post-Tertiary Fossiliferous Beds of Scotland. *Trans. Geol. Soc. Glas.*, 4, pp. 32–45.

40. Robertson, D. and Crosskey, H. W. 1874. On the Post-Tertiary Fossiliferous Beds of Scotland. *Trans. Geol. Soc. Glas.*, 4, pp. 128–37.

41. Smith, J. 1862. *Researches in Newer Pliocene and Post-Tertiary Geology*. Glasgow.

42. Robertson, D. and Crosskey, H. W. 1874. On the Post-Tertiary Fossiliferous Beds of Scotland. *Trans. Geol. Soc. Glas.*, 4, 241–56.

43. Peach, B. N. and Horne, J. 1917. The Bone Cave in the Valley of Allt-nam-Uamh, near Inchnadamff, Assynt, Sutherland. *Proc. Roy. Soc. Edin.*, 37, pp. 327–49.

44. Summarised with bibliography by J. Geikie. 1874. *The Great Ice Age*. First Edition. London. pp. 558–9.

45. Haswell, J. 1866. Glacial Clay at Cornton, near Bridge of Allan. *Geol. Mag.*, 2, p. 182.

46. Gray, A. 1894. Notice of the Discovery of a Cinerary Urn of the Bronze Age, and of Worked Flints underneath it at Dalaruan ; also of an Old Flint Working-place in the 30-foot Raised Beach at Millknowe, Campbeltown. *Proc. Soc. Ant. Scot.*, 28, pp. 263–74.

47. Garrod, D. A. E. 1926. *The Upper Palaeolithic Age in Britain*. Oxford.

48. Jackson, J. W. 1909, 1911, 1913. Reports on the Exploration of Dog Hole Cave, etc. in *Trans. Lancs. and Ches. Antiq. Soc.*, 27, pp. 1–32 ; 28, pp. 59–81 ; 30, pp. 99–132.

49. Eastwood, T., Dixon, E. E. L., Hollingworth, S. E. and Smith, B. 1931. The Geology of the Whitehaven and Workington District. *Mem. Geol. Surv. Eng. and Wales.*

50. Ritchie, J. 1920. *The Influence of Man on Animal Life in Scotland.* Cambridge.

51. Smith, J. A. 1857. Horns of *Cervus tarandus* in Dumbartonshire. *Proc. Roy. Phys. Soc. Edin.*, 1, pp. 163, 247.

52. Jack, R. L. 1876. Notes on a Till or Boulder Clay with Broken Shells, in the Lower Valley of the River Endrick, near Loch Lomond, and its Relation to certain other Glacial Deposits. *Trans. Geol. Soc. Glas.*, 5, pp. 5–25.

53. Simpson, J. B. 1933. The Late-Glacial Readvance Moraines of the Highland Border west of the River Tay. *Trans. Roy. Soc. Edin.*, 57, pp. 633–46.

54. Tait, D. 1934. Excavations in the Old Lake Deposits at Corstorphine during 1930–32. *Trans. Edin. Geol. Soc.*, 13, pp. 110–25.

55. ———. 1930. Excavations under the Sea at Portobello. *Trans. Edin. Geol. Soc.*, 12, pp. 313–20.

56. Lacaille, A. D. 1948. The Deglaciation of Scotland and the Forming of Man's Environment. *Proc. Geol. Assoc.*, 59, pp. 151–71.

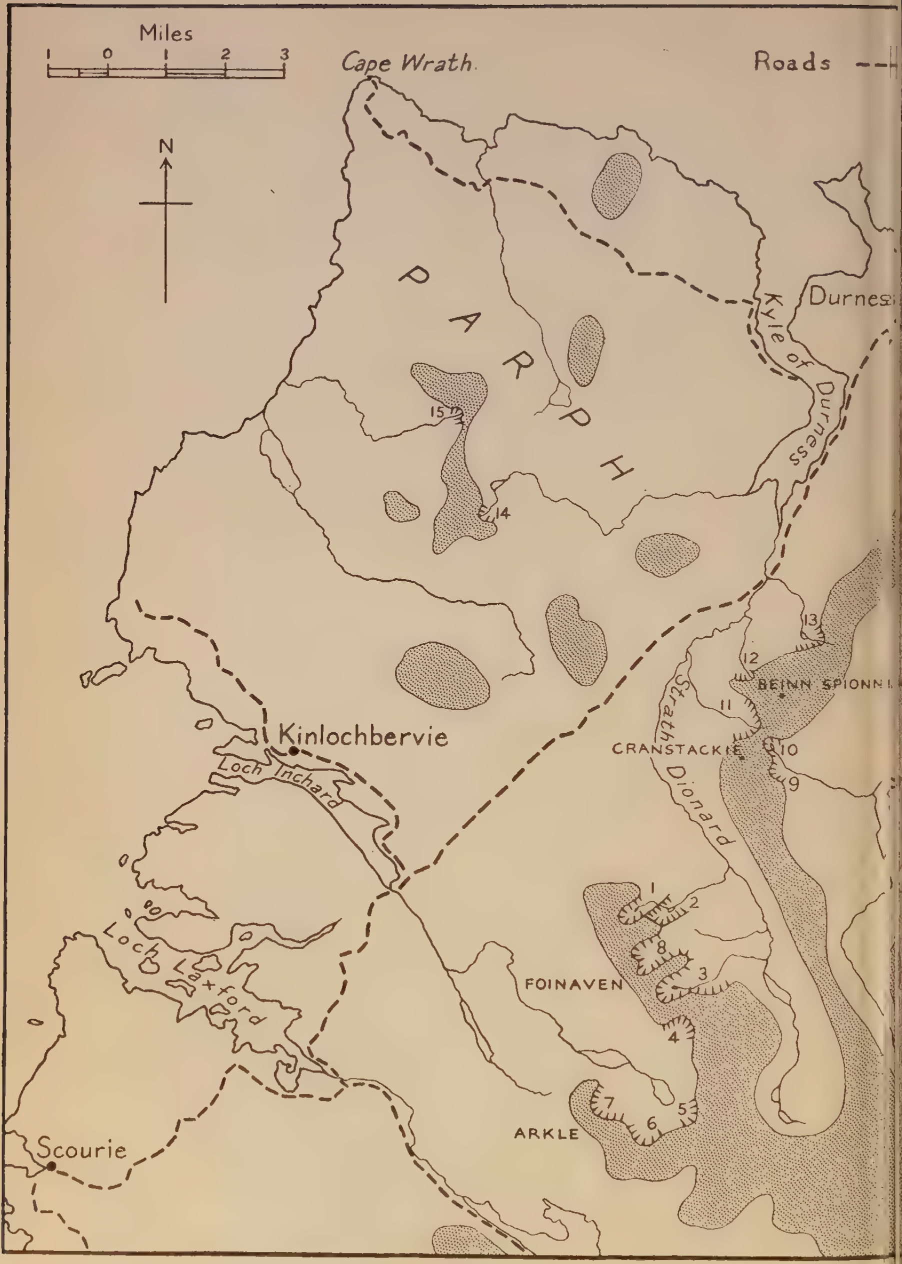


FIG. 1.—Distribution of corries, which are numbered as in text. Stipple shows generalise of high land. Based upon the Ordnance Survey map, with the sanction of the Cont H.M. Stationery Office.

To face p. 145.]

SOME CORRIES OF NORTH-WEST SUTHERLAND

BY H. R. THOMPSON

[*Received* 18*th June*, 1949]

ABSTRACT.—Thirteen corries were investigated near Cape Wrath. Five contained lochans, the depths of which were ascertained. All the corries were formed in Lewisian gneiss and—or—Cambrian quartzite and their detailed development was closely related to the distribution and relative resistance of these rock types. However, the gneiss, though normally the more resistant of the two, was in places found to have been weakened by shatter-planes, the erosional exploitation of which has led to the formation of rock basins.

THE observations which follow were made by the members of a small scientific training expedition in July 1948. The area concerned is the western part of the parish of Durness which was described in the *Scottish Geographical Magazine* for September 1947 [3].*

The corries which were investigated lie on both sides of the Foinaven Range and along the Cranstackie–Beinn Spionnaidh ridge. Both ridges consist in the main of Lewisian gneiss capped by Cambrian quartzite and rise steeply to nearly 3000 feet on either side of Strath Dionard.

Each corrie will be described in turn, its first mention being accompanied by the number by which it is indicated on Fig. 1 and by a six-figure reference to Sheet 9 of the Ordnance Survey one-inch map of Scotland. The descriptive section is followed by a discussion, the main points of which are summarised in a list of conclusions.

FOINAVEN

Eight corries were noted on this range.

Coire Ghranda (No. 1 : 320514) which lies at its north-eastern end, is 1000 yards long and more than 600 yards wide from clifftop to clifftop. The floor of the corrie has an altitude of 1700 feet, while the col at the head is 1000 feet higher and the culminating peaks of the Foinaven Range (2980 and 2952) lie at the top of each side-cliff. These cliffs, which are continuous all round the corrie, are extremely fine and consist of Lewisian gneiss which is one of the most resistant of all rocks. The upper parts are frost-shattered, but the lower slopes are formed of ice-smoothed slabs. The dividing line is prominent and was found to be 470 feet above the floor, near the outlet.

The floor itself, which also consists of gneiss, is by no means flat. There are three distinct basins, one of which contains a lochan 130 yards long. This is 20 feet deep in the centre and is not round, as might be expected, but diamond-shaped (Fig. 2). It is a true rock basin and lies on a prominent shatter-plane which runs right down the middle of the corrie. The excavation of the basin—presumably the work of moving ice—was undoubtedly facilitated and perhaps even caused by the occurrence of this line of weakness. The alternative explanation, that a snow-bed may have lain here and slowly eaten away the rock by nivation, is much less satisfactory. Whatever its origin, the incidental nature of the basin on the large uneven expanse of the corrie floor must be emphasised.

---

* For list of References see p. 155.

Apart from its cliffs, the most satisfying feature of Coire Ghranda is its rock lip which is most impressive, especially when viewed from outside. The corrie is extremely "clean," there being practically no vegetation, no moraines and very little other debris, apart from some savage quartzite scree at the head, streaming down from the Foinaven summit ridge.

The outlet burn has eaten its way down the line of the major shatter-plane and penetrates the lip in a narrow gorge. Four hundred yards downstream it makes a right-angled bend from the shatter-plane to a joint-plane and then descends south-eastwards by a waterfall and a series of miniature rapids to **Coire Duail** (No. 2 : 328513). Parallel with the burn there is a splendid expanse of polished and sapped gneiss slabs over which the ice slid, as it swung round and fell some 500 feet into the basin below. Coire Ghranda thus hangs above and, as it were, in the back right-hand corner of Coire Duail.

At first sight **Coire Duail** appears to bear very little relation to the text-book conception of a corrie, for it has cliffs only at its head—even then, they run diagonally, in accordance with the line of flow of the former glacier—and it has much lower banks on either side. But further inspection reveals a corrie-shaped hollow that has been to a certain extent filled in by pro-talus, alluvium and moraines. It is 800 yards long by 600 yards across. The altitude of its bed is 990 feet and the cliffs at its head rise some 850 feet sheer. Ice-smoothed slabs are visible about half-way up the cliffs, but below they are masked by detritus of various kinds.

There is a moraine-dammed lochan which, though 250 yards long, was found to have a maximum depth of only 15 feet (Fig. 3). The lochan was once larger but the outlet burn has cut down through the moraine and is now flowing over solid rock which was observed at one place to be at the surface level of the lochan. Overdeepening was suspected but not proved.

Coire Duail has a green and idyllic beauty which contrasts strongly with the bare greyness of Coire Ghranda. This is due to the presence of abundant downwash and morainic material which supports a comparatively rich and flourishing vegetation.

The outlet burn, having no convenient shatter-plane to exploit,

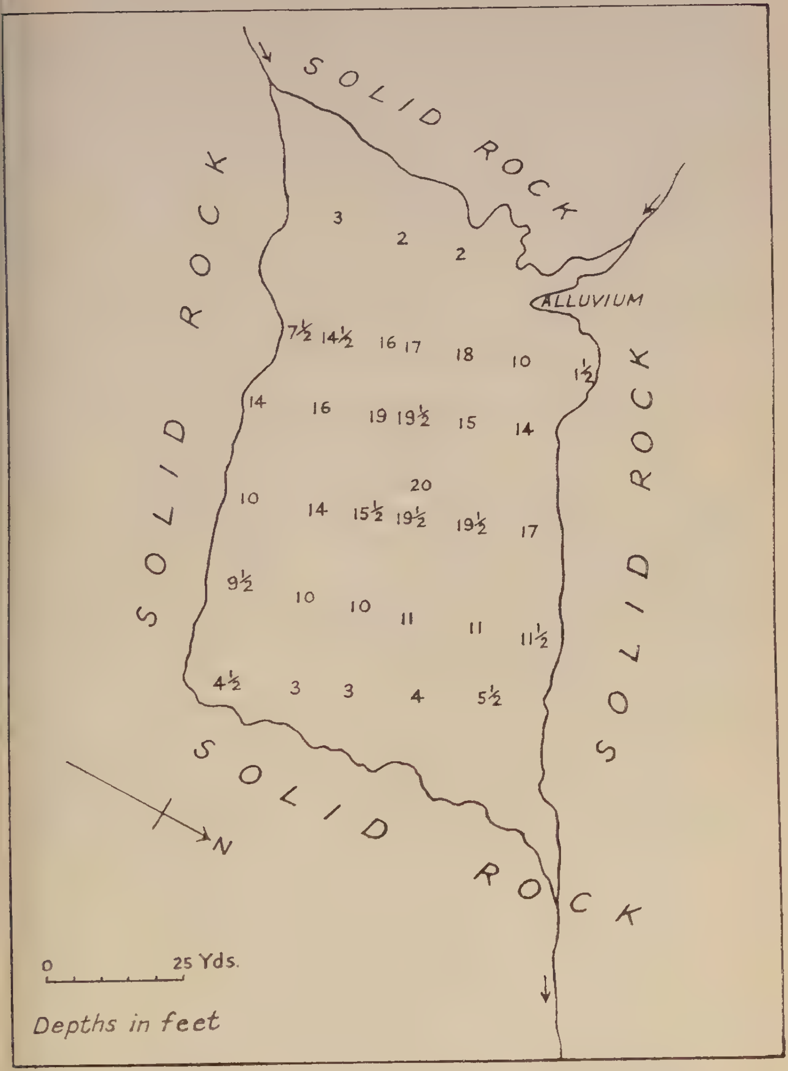


FIG. 2.—LOCHAN OF COIRE GHRANDA. (No. 1 on Fig. 1).

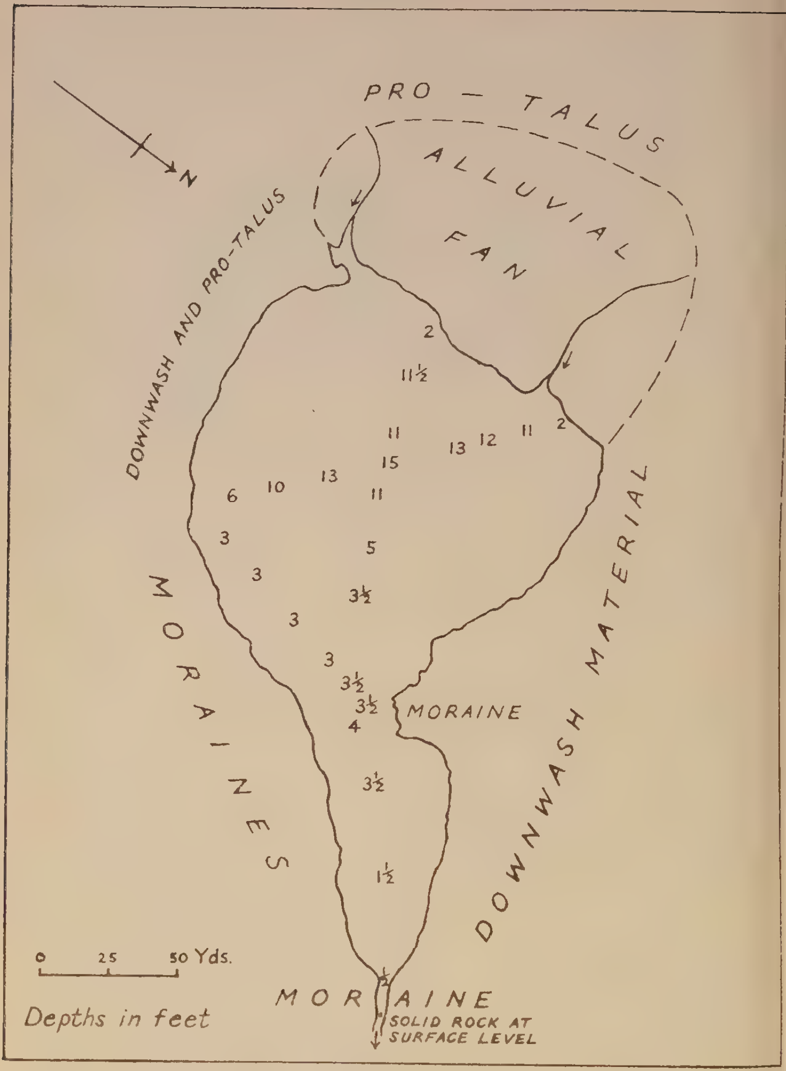


FIG. 3.—LOCHAN OF COIRE DUAIL. (No. 2 on Fig. 1).

flows over ice-polished slabs for 1¼ miles, as it descends nearly 660 feet to the River Dionard. A walk of 1½ miles upstream over blanket bog brings one to the portals of **Coire na Lurgainn** (No. 3 : 329492). This corrie differs greatly from the two previous ones, for it has been formed entirely in Cambrian quartzite, a sharp brittle rock, notorious for its unstable screes. The bottom of the corrie, which contains a lochan 70 yards long but only 3 feet deep, lies in unmoved debris-strewn basal quartzite, but the cliffs on either side and at the head consist of imbricately-thrust and contorted " pipe-rock " quartzite which was involved in the Caledonian earth-movements. The cliffs to the south rise nearly vertically from 1500 to 2400 feet and the beautiful peak at the head sweeps up to 2663 feet. But on the north side there is a step formed by the basal quartzite, and the knife-edge ridge of A' Cheir Ghorm which lies on top of this, is set well back, giving the corrie an asymmetrical cross-section.

The lower slopes are everywhere draped with scree and if there is a hollow bottom it is filled with debris. No ice-smoothed slabs are visible.

Coire na Lurgainn is not technically impressive as a corrie, though it is scenically very fine, being largely devoid of vegetation.

The narrow col at its head leads over to the **Arkle amphitheatre** (Nos. 4, 5, 6, 7 : 320460). Here are four semi-circular corries, with a big loch common to them all. The cliffs, which are almost entirely of quartzite, are well-developed, but the floors, consisting as they do of gneiss, seem to have yielded very little to ice erosion and slope downwards and outwards, there being no trace of rock steps or overdeepening in the individual corries. It is probable, however, that the hollow occupied by the big loch may have been at least partially the work of ice.

On the east side of Foinaven, between Coire Ghranda and Coire na Lurgainn, there is a **compound corrie** (No. 8 : 323501) which is even less satisfactory than that of Arkle. It would appear that frost-shattering and the consequent recession of the quartzite walls have alone shaped the present feature. The gneiss bed—part of a miniature plateau—is apparently little eroded, perhaps because of the lack of a pre-glacial river-head comparable in size with those which must have formed the bases of the adjacent corries.

CRANSTACKIE AND BEINN SPIONNAIDH

Across the Dionard from Foinaven lies a long ridge which culminates at its northern end in the peak of Cranstackie (2630 feet). Biting into the hillsides around its base are three corries.

The first, a **nameless dry corrie** (No. 9 : 362551), has semi-circular gneiss and quartzite walls which are neither particularly steep nor particularly high. The bottom consists of an outward-sloping gneiss platform covered with quartzite debris, there being

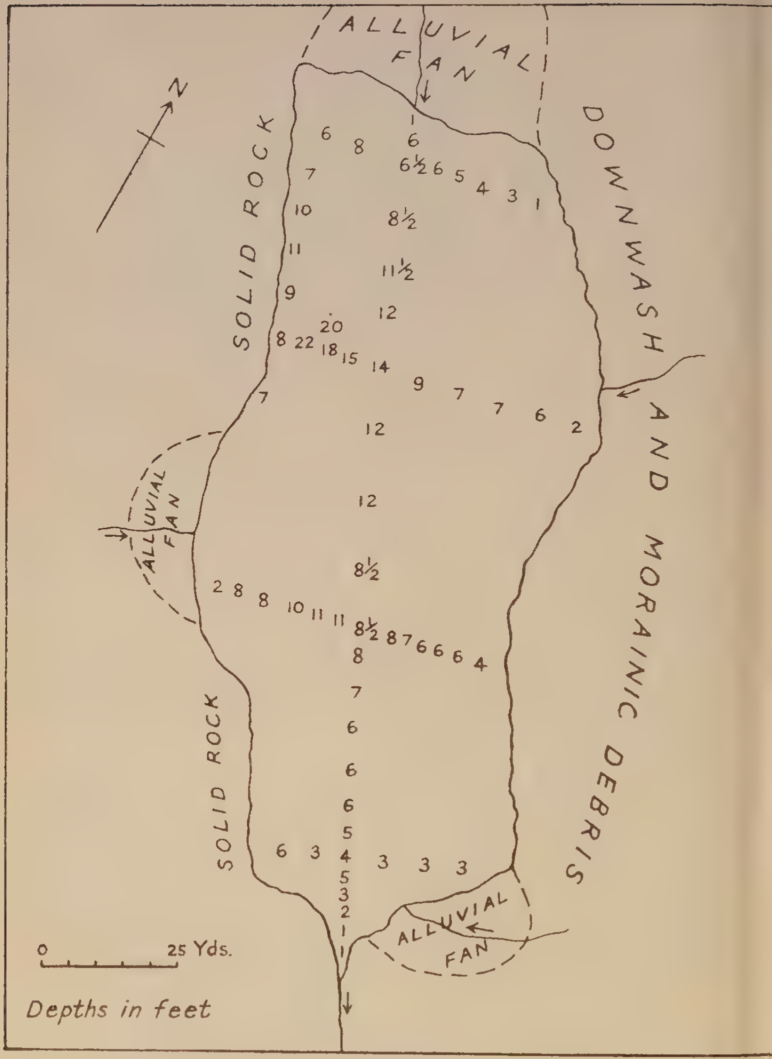


FIG. 4.—LOCHAN OF COIRE AN UINNSEINN. (No. 10 on Fig. 1).

no trace of overdeepening and no semblance of a rock step. The only moraines are farther down the slope towards Loch Eriboll. Vegetation is scant on the bottom but has obtained a hold on the lower parts of the walls.

As one crosses this corrie from south to north, one sees ahead a solid gneiss barrier some 150 feet high, on the face of which is a waterfall issuing from a deep-sunk burn. Behind this barrier and set low down amidst beautiful green surroundings is the lochan of **Coire an Uinnseinn** (No. 10 : 358557). The south-west side of the lochan, which is 160 yards long, is formed by two low vertical faces of gneiss, separated by a burn, while the north-east side shows no rock *in situ* and is contained by morainic debris and downwash.

There is so much debris of one sort or another in the corrie as a whole (which is 400 yards by 300 yards), that it is extremely difficult to determine whether or not any cliffs are present. What cliffs there are must certainly be comparatively low and gentle. And yet the general shape is undoubtedly that of a corrie, while the gneiss barrier and the depth of the lochan—22 feet, close to the south-west shore—strongly suggest overdeepening by some erosive agent (Fig. 4). The outlet burn flows along a shatter-plane ; and the long narrow shape of the lochan, together with the presence of the vertical faces of gneiss, strongly indicate that the shatter-plane continues towards the head of the corrie and consequently that this basin was formed in the same way as that of the lochan of Coire Ghranda.

At the head of Coire an Uinnseinn is a col which leads over into **Calbhach Coire** (No. 11 : 347567). This is a very large dry corrie (1500 yards by 1000 yards), having 500-foot gneiss cliffs all round. Its peat-bog filled bottom is apparently below the level of the solid gneiss lip which hangs 600 feet above Strath Dionard. The outlines have been much softened by vegetation and downwash, but it is nevertheless a remarkably satisfying example of a hanging corrie.

Half a mile farther north, at the foot of Beinn Spionnaidh, is a feature which might be regarded as an embryo corrie (No. 12 : 350583). It would appear to be a gully which had only partially been rounded into corrie form before the end of the Ice Age. It retains an elongated shape, but there has developed a " young " lip whence a waterfall plunges 250 feet to the Strath floor.

A mile and a quarter farther north still, lies **Loch na Seilg** (No. 13 : 368588). There are gneiss cliffs here which, though by no means good corrie walls—they are neither steep nor continuous enough—do present a general corrie form. Twenty-one feet of water was found in the loch (350 yards long), and it is thought that there may be a solid rock lip, as well as a prominent moraine, near the outlet (Fig. 5). Vegetation cover is extensive, though monotonous in character, and hampered the search for solid rock during the short time which we had available.

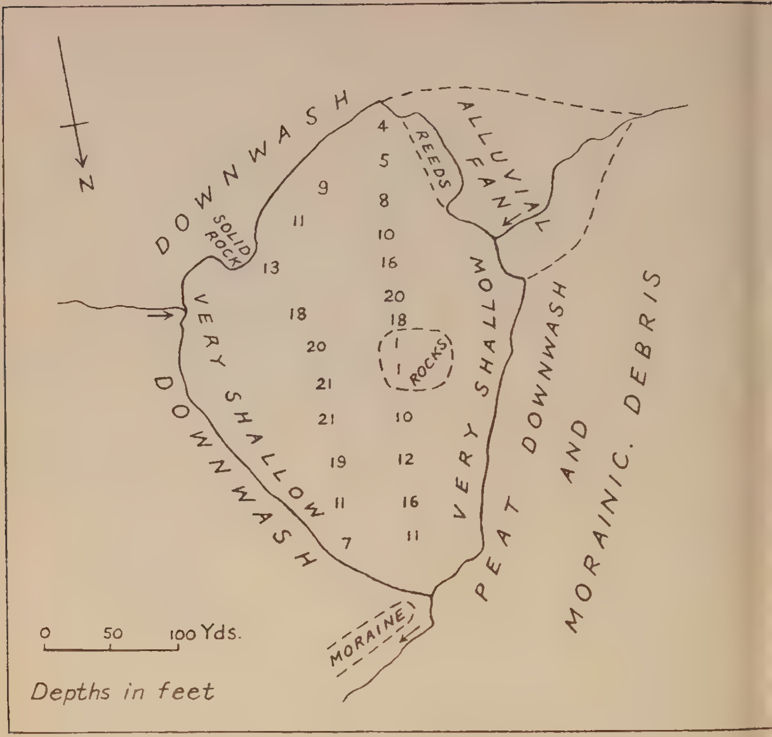


FIG. 5.—LOCH NA SEILG. (No. 13 on Fig. 1).

PARPH

Four excursions towards the centre of the Parph were carried out in order to determine whether or not corries were present among the Lewisian gneiss and Torridonian sandstone hills. To our considerable surprise, no real corrie was found, most of the related features being little more than large river source-basins. All were deeply mantled with peat. Were two of them (Nos. 14 and 15 : 274653 and 287627) to be swept clean, they might prove to be corries ; but it appeared rather unlikely.

DISCUSSION OF THE EVIDENCE

It will be seen from the foregoing account that no true text-book corrie is to be found in the region. In some, the walls are satisfactory, while the floor is not. In others, the converse is the case. All the lochans are shallow, none containing more than 22 feet of water. and, in this, contrast with those which have been sounded in the Lake District and found to be 60 feet and 209 feet deep (Easdale and Bleawater Tarns).

The Sutherland mountains are slightly lower than those of the Lakes and are also a few miles nearer the sea ; their corrie stage of glaciation may therefore have been shorter. But, on the other hand, Phemister [**4**, p. 88] indicates that Foinaven (" the Reay Forest ") was one of the four major ice-centres of the Northern Highlands towards the end of the last glacial period. It is moreover some 270 miles farther north than the English mountains. The differences in depth of the lochans of the two areas are consequently very difficult to explain. In the absence of fuller details of the investigations in the Lake District, it would appear that the reason for the relative lack of development of the Sutherland corries may be found not in climatology but in geology.

In the notes on the individual corries some remarks were made about the respective weathering qualities of gneiss and quartzite. These qualities are perhaps best illustrated in the Arkle amphitheatre of which the excellent quartzite walls surround an apparently little-modified gneiss floor.

The quartzite walls of Coire na Lurgainn, the compound corrie, and to a lesser degree those of the nameless dry corrie, while not entirely satisfactory from the point of view of shape, also display the effects of frost-shattering on a large scale. With the exceptions of Coire Ghranda and the head wall of Coire Duail, the cliffs made of gneiss are by no means as steep and continuous as those of the quartzite. In the two exceptional cases, as might be expected from their location on Foinaven itself, frost-shattering is much in evidence and the cliffs are steep.

Gneiss forms the floors of 12 of the 13 corries which have been mentioned. Hollow beds and rock lips definitely occur in two cases (Ghranda and Uinnseinn) and possibly in three more (Duail, Calbhach and Seilg). Of the remainder, the compound, nameless and embryo corries have certainly not been overdeepened, while the uncertain origin of the Arkle amphitheatre loch and its connection with the surrounding corries have already been mentioned. It is evident that, in the majority of cases, the gneiss floor has not readily lent itself to excavation. It is therefore suggested that advanced development of gneiss corries may often be explained by the presence of shatter-planes such as were observed in Coire Ghranda and Coire an Uinnseinn and are found in swarms to the west of Foinaven [cf. **4**, p. 13]. The latter area also provides abundant evidence as to the formation of rock basins in the gneiss, which are seen to occur only along joint- and shatter-planes and especially at shatter-plane junctions. It is further suggested that the exploitation of the shatter-planes by Pre-Glacial rivers was of great assistance to the glaciers of the Ice Age in their erosive action on the corrie beds.

Only in Coire na Lurgainn, where there is no visible hollow bed, does quartzite form the floor of a corrie. But since it is believed that there is a gneiss platform at no great depth below the surface, deductions as to the nature of quartzite floors in general would not be justified.

No attempt will be made to explain the lack of corries in the Parph. Our visits were too short to permit the collection of sufficient data and space does not allow of speculation here.

CONCLUSIONS

The conclusions which may be drawn from this study of the corries of north-west Sutherland are as follows :

(1) Quartzite breaks up more readily than does gneiss under the forces of melting and freezing.

(2) The effects of moving ice on gneiss—whether at the bottoms of corries or elsewhere—appear to have been largely confined to polishing and sapping. Its effects on quartzite were not observed on a large scale, but are thought to be rather greater than those on gneiss.

(3) The development of the individual corries has thus depended to a large extent on the distribution of the two types of rock. The lack of complete development of the corries of the area as a whole has been in some considerable degree due to the resistant qualities and almost universal presence of Lewisian gneiss. The gneiss however is thought to have been weakened in places by the presence of shatter-planes.

(4) Altitude, latitude, precipitation, proximity to the sea and the intensity and duration of the glacial periods, are, as always, most important factors.

(5) Most of the corries were originally stream-heads which were cleaned out by glaciers and widened and lengthened mainly by the process of thawing and freezing of meltwater [**1** ; **2** and **5**]. They are best developed on Foinaven itself where frost-shattering is most apparent and not necessarily where the moving ice was deepest, nor in connection with any particular orientation. (Fig. 1.)

(6) Rock basins in corrie floors, now in some cases occupied by lochans, may possibly have been formed in Pre-Glacial times, but were more probably excavated by debris-armed ice, the movement of which may have taken the form of rotational slipping [**5**, pp. 126–8]. The shatter-planes of the Lewisian gneiss are of great importance in this connection.

NOTES

The soundings shown on the accompanying maps of four of the corrie lochans were made from an R.A.F. M-type rubber dinghy. In the cases of Coires Ghranda and Duail, white numbers were painted round the edges and runs carried out between opposite pairs of numbers. Soundings were made when pairs of cross-bearings came into line. The paint marks, and consequently the positions of the soundings, were located by means of a plane-table survey which also included a number of points on the corrie cliffs. The unfavourable weather did not allow of surveys of Coires Uinnseinn and Seilg, but the outlines of their lochans have been drawn from air- and ground-photographs and the positions of soundings marked as accurately as possible.

The author wishes to record the important part played by T. A. M. Gardner, geologist of the 1948 Expedition, in the collection of the information set out in the above article.

REFERENCES

1. ODELL, N. E. 1937. The Glaciers and Morphology of the Franz Josef Fjord region of North-East Greenland. *Geogr. Journ.*, 90 (Esp. pp. 246–50).
2. LEWIS, W. V. 1938. A Meltwater hypothesis of Cirque Formation. *Geol. Mag.*, 75, pp. 249–65.
3. HOBSON, P. M. 1947. Durness Parish. *Scot. Geog. Mag.*, 63, pp. 71–83.
4. PHEMISTER, J. *Scotland : The Northern Highlands* (*British Regional Geology*), 2nd ed., 1948.
5. LEWIS, W. V. 1949. The Function of Meltwater in Cirque Formation : a reply. *Geogr. Rev.*, 39, pp. 110–28.

WHITSUN FIELD MEETING AT LYME REGIS

14th–17th May, 1948

Report by the Directors: T. Barnard, Ph.D., F.G.S., and J. G. Capewell, B.Sc., F.G.S.

[*Received* 10*th June*, 1949]

Friday, 14th May

THE party, which numbered 30, assembled in the evening at the Philpot Museum (made available through the courtesy of the Town Clerk, Lyme Regis) and an introductory talk and discussion on the area was held. Headquarters were at the Clarence Hotel, but some members were accommodated at the Gables Hotel.

Saturday, 15th May

The general features of the coast having first been pointed out from Church Cliffs, Lyme Regis, the party travelled by coach via Charmouth to Morecombelake, whence Dr. W. D. Lang[1] led the way to the flat summit of Hardown Hill. Here he outlined his interpretation of the history of the Char Valley. The Cretaceous chert beds were visited before the party rejoined the coach, which then drove to Seatown, where lunch was taken. Afterwards, during the rather arduous walk along the beach westwards to Charmouth, the fine cliff sections under Golden Cap and Stonebarrow were studied. The Green Ammonite Beds, the Belemnite Marls and the Black Ven Marls of the Lower Lias were examined and many characteristic specimens obtained. The Three Tiers and succeeding Middle Lias, and the transgressive Createaceous were also indicated in the upper part of the cliffs. At Charmouth the position of the fault throwing Shales-with-Beef against the Black Ven Marls was pointed out, but the contortions in the Marls were not clearly exposed due to sand accumulation. Tea was taken at Charmouth and a vote of thanks accorded to Dr. Lang. Afterwards the party travelled back to headquarters by coach, a few members walking along the shore.

Sunday, 16th May

Leaving by coach, the party went directly to Eype Mouth, whence the geology of the cliffs eastwards for two miles was ininvestigated. In Walton Cliff, the Middle Lias, the Junction Bed and the Down Cliff Clay of the Upper Lias were pointed out at " Fault Corner " where they are thrown by an east–west fault against Middle Jurassic beds. These comprise the Fuller's Earth Clay, the

---

[1] Dr. Lang's description of the development of the Char valley is given separately as a contribution to the present Field Report.

Boueti Bed, overlain by grey clays and shelly limestones of the Forest Marble. *Ostrea hebridica* Forbes var *elongata* Dutertre was found in abundance.

The cliff was scaled at this point and the cliff-top path over the outcrop of the Forest Marble was followed to Bridport Harbour (West Bay). Continuing to the foot of East Cliff, the party examined the Bridport Sands, well exposed here, and the diachronous nature of these deposits was discussed. The accumulation of beach shingle at this point was also noted, as large quantities are carted away, to be replenished apparently by longshore movement westward from the Chesil Beach. The evidence for an east–west fault through West Bay was also indicated.

The coach was then rejoined and the pits of the Bothenhampton Brick and Tile Works were visited. These are in Kelloways Clay and a small fauna was obtained. The clay here is allowed to weather, and by the reaction of its oxidised sulphide content with calcareous matter, idiomorphic selenite crystallises out, and many good specimens were collected.

The coach then passed through Bridport across the Lias country to the quarries at Horn Park, west of Beaminster. Here a rich and plentiful fauna was found in the Murchisonae Zone of the Inferior Oolite. After tea in Beaminster the homeward journey was made via Broadwindsor to Pilsdon Pen. From the summit of the hill an excellent view was obtained, especially of the Vale of Marshwood, which had been seen the previous day from Hardown Hill.

Thence the journey was made without interruption via Birdsmoor Gate, along the Greensand plateau to Hunter's Lodge and down to Lyme Regis.

Monday, 17th May

The party again left by coach and a halt was soon made at the entrance to Pinhay House, where Major Allhusen met and kindly escorted the members to the shore at Pinhay Bay, pointing out many features of botanical interest on the way. Here the fault was noted in the cliff, and the Rhaetic (" White Lias ") and the Blue Lias were examined, fossils being collected from the latter. The problems of the sedimentation of these beds provoked some discussion.

Returning by the same route to the main road the party travelled by coach westwards across the valleys of the Axe, the Sid and the Otter to Budleigh Salterton, the general geological features being pointed out en route. After lunch, the famous Pebble Beds, regarded as the base of the Trias, were visited and examined, and the salient features of the sedimentation of the New Red rocks of south-west England discussed.

On the return journey from Budleigh Salterton, a halt was made at White Cliffe, a mile to the west of Seaton. Here on the west side of a fault a clear succession of the Upper Greensand and the Lower and Middle Chalk was observed and the fallen blocks at the foot of the cliff yielded a fauna from these beds. The Keuper Marl on the east or upthrow side of the fault was briefly examined and the party then walked along the shore to Seaton. A vote of thanks to the Directors and Secretary (Miss E. Joan Turner, B.Sc.), was proposed by the President, Mr. E. E. S. Brown, M.B.E., and seconded by the Secretary for Field Meetings, Dr. G. W. Himus.

The journey back to Lyme Regis was made via the Axe Valley, the physical features of which were noticed, to Axminster, where several members had to catch the evening train back to London. The rest continued to Lyme and left the following day.

LANG, W. D. 1932. The Lower Lias of Charmouth and the Vale of Marshwood. *Proc. Geol. Assoc.*, 43, p. 97–126.

——— and DIGHTON THOMAS, H. 1936. Report of Whitsun Field Meeting in Lyme Regis District. *Proc. Geol. Assoc.*, 47, p. 301–315.

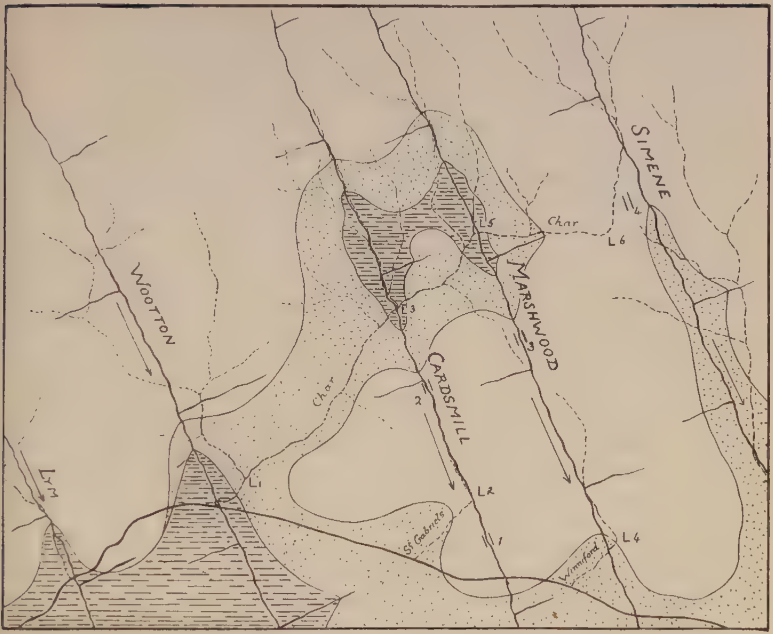
THE POST EOCENE DEVELOPMENT OF THE VALLEY OF THE CHAR

By W. D. Lang, Sc.D., F.R.S.

The history of the Char Valley began after Eocene times, when the Post-Cretaceous peneplain was uplifted. The axis of this uplift lay away to the north, and its direction was approximately WSW.–ENE. Thus, the consequent drainage flowed NNW.–SSE. ; and five of these consequent streams were considered, namely, from west to east, the ancestral Lyme stream, Wootton stream, Card's Mill brook, Marshwood brook (including the Middle brook) and Simene [2*]. The spot where the party stood lay in the line of the Card's Mill brook, and overlooked the gap made by the ancestral stream at Morecombelake. Thence the line could be seen to follow the upper half of St. Gabriel's Water, and to continue to the gap behind Golden Cap. The lower half of St. Gabriel's Water, flowing approximately NE.–SW., was formerly a tributary of the ancestral Wootton stream—the next consequent stream on the west. Its original subsequent direction, namely, ENE.–WSW., was deflected along the more easily followed line of strike of the Lias—NE. to SW.—after the stream had cut down through the Cretaceous. As this subsequent stream cut back, it met the Card's Mill consequent at the point marked now by the elbow-bend half-way down the St. Gabriel's valley, thus capturing the upper part of the Card's Mill consequent and causing the gap behind Golden Cap to become dry.

The same process happened on the Winniford, whose upper half is part of the ancestral Marshwood and Middle brook consequent, and whose lower half was a subsequent tributary of the ancestral

[*] For list of References see p. 160.



EXPLANATION TO FIG. 1

Diagrammatic map of a supposed early stage in the development of the River Char and neighbouring streams.

In addition, the present coast is indicated by a thick continuous line near the bottom of the map ; and the present streams are shown by broken lines.

Five supposed consequent streams, namely, the ancestral Lym, Wootton, Card's Mill, Marshwood (including Middle) and Simene brooks, are shown cutting channels in the original southward-sloping peneplain of Upper Greensand (plain) which, in places, they have denuded and have reached the underlying Upper and Middle Lias sands and loams (stippled), and even cut down to the Lower Lias clays (horizontally lined). Because both the Greensand and Lias form domes over the Vale of Marshwood, the Lower Lias is reached there at an early stage, and the consequent streams, crossing the Lower Lias, meet and traverse the Middle Lias and Greensand again on the southern margin of the Vale.

The subsequent streams ancestral to the Winniford and St. Gabriel's Water have captured the consequent ancestral Marshwood and Card's Mill brooks, respectively, at the elbow-bends L_4 and L_2 ; while L_1, L_3, L_5, and L_6 mark elbow-bends where the subsequent streams, which together form the composite River Char, have, respectively, captured the Wootton, Card's Mill, Marshwood, and Simene consequents.

Gaps which have been consecutively left dry by these captures are marked as follows : (1) Golden Cap (*circa* 450 feet), (2) Morecombelake (*circa* 400 feet) (3) Ryall (*circa* 280 feet), and (4) Simene (*circa* 180 feet).

Card's Mill brook which, cutting back, captured the Marshwood brook consequent at a point now marked by the elbow-bend made by the Winniford between Chideock and Seatown.

Again, a subsequent tributary of the Lym ancestor cut back and captured the ancestor of the Wootton stream near the present mouth of the Char; and a subsequent tributary of the Wootton stream beheaded the ancestral Card's Mill brook near Whitchurch, and caused the Morecombelake gap to become dry. The same process beheaded the Marshwood brook north of Ryall and thus dried the Ryall gap. Lastly, the Simene was beheaded by a subsequent tributary of the Marshwood brook at the south-east corner of the Vale where now the Char turns from the original consequent (NNW.–SSE.), to the subsequent direction, but a direction modified by the strike (E.–W.) of the Lias at this point.

It is notable that the heights of these four gaps, which can now be seen, indicate the sequence of events. The highest, and therefore earliest formed, of the four, is the Golden Cap gap, about 450 feet; the next, the Morecombelake gap, about 400 feet; lower still, the Ryall gap, about 280 feet; and the lowest, the Simene gap, about 180 feet.

The party then followed the northern rim of Hardown Hill overlooking the greater part of the Vale as far as its eastern end and the Simene gap. Jukes-Browne [**1**] accounted for the basin-like shape of the Vale as due to the Cretaceous beds forming a dome with its apex lying over the middle of the Vale.[1] Thus, when the consequent streams cut down as low as the Lias clays beneath the apex of the dome, they would have to meet and re-traverse the Middle Lias and Cretaceous beds before leaving them behind, and the Lias at first would form an isolated patch surrounded by Cretaceous beds. The denudation of the Lias clay would be comparatively rapid and would be helped by springs causing founders at the clay-sandy junctions. So the patch of Lias clay on the middle of the Vale would rapidly enlarge to form the basin-shaped feature which it now presents. Jukes-Browne also first intimated that the Winniford once flowed over the Ryall gap.

The walk back to Morecombelake was made along the eastern horn of Hardown Hill overlooking the Ryall gap.

REFERENCES

1. JUKES-BROWNE, A. J. 1897. *Proc. Dorset Nat. Hist. and Ant. Field Club*, 18, pp. 174–84 (reprinted with some alterations in 1898, *Geol. Mag.*, dec. iv, vol. v, pp. 161–68).
2. LANG, W. D. 1926. *Proc. Geol. Assoc.*, 37, pp. 199–205.

---

[1] The Lias was also domed here, before the Cretaceous was deposited, thus causing its lower beds to appear sooner in the middle of the Vale than they would have if only the Cretaceous beds had been domed.

FIELD MEETING AT BARTON AND MILFORD-ON-SEA, HANTS

Saturday, 21st May, 1949

Report by the Directors: E. St. John Burton, F.L.S., F.R.S.A., F.G.S., Amer. G.S., and D. Curry, M.A., F.G.S.

[*Received 7th July,* 1949]

A PARTY of about 30 members assembled at the Cliff Café, Barton-on-Sea, and then walked to the cliff edge, where the Directors gave a short account of the geology of the Hampshire Basin with particular reference to the magnificent panorama of the coast and to the strata to be studied during the day.

They pointed out that the cliff sections to the west of where they stood had deteriorated seriously in the past 15 years to such an extent that good clear sections of the Middle and Lower Barton Beds were now very seldom seen. As a result, the party would concentrate on the exposures of the Upper Barton and the Headon Beds, to the east, which were still in fair condition. This deterioration, affecting the most fossiliferous horizons of this classical type section, was attributed at Barton to the erection of groynes, and the cutting of drainage channels in the cliff, and at Highcliffe, possibly also to the accumulation on the shore of the vast mass of sand and shingle formerly held out to sea by the flow of water draining Christchurch Harbour. This was released to move landwards by the breaching of the bar about 15 years ago. (These explanations may have to be reviewed after we see the effects of a few really wet winters.)

The party then moved down to the beach, where the upper grey-brown clays of the Middle Barton Beds were fairly well exposed, overlain by the blue-grey sandy clay with abundant *Chama squamosa*, Sol., which forms the base of the Upper Barton Beds. A considerable number of fossils was collected from both horizons, and the party then moved along the beach to the east, making a stop at Becton Bunny for lunch. The dark grey clays of the *Olivella branderi* bed, and the succeeding pale Long Mead End sands were next examined and it was pointed out that these uppermost Barton Beds gradually lose their marine characters, as increasing quantities of estuarine fossils are seen to occur in successively higher beds. The party was fortunate in seeing the actual junction with the overlying freshwater beds of the Lower Headon series and was able to observe the gradual change from marine to freshwater conditions which the beds display.

Continuing their progress eastwards, the party collected from various fossiliferous horizons of the Lower Headon Beds, and a good series of mollusca was obtained. Scales of the ganoid fish, *Lepidosteus*, and fragments of crocodile and turtle bones were found, and a small mammal tooth, probably of the rodent, *Theridomys*. When the uppermost beds of the Lower Headon series had been traversed, the party split into two. Some members ascended the cliff to catch the bus back to New Milton station, while others continued eastwards to examine the much-disputed estuarine deposit which overlies the Lower Headon Unio Bed in the cliff immediately south of the Solent Court Hotel at Milford-on-Sea. This consists of a fossil shell-bank not more than a foot thick, with a fauna which is matched most closely in the "Venus" Bed at Colwell Bay, but contains also a few species special to it, and some almost certainly derived from the beds below. The bed is not normally exposed, but a face had been cleared specially for the party and a representative collection of fossils was made from it.

The party re-joined at the Doran Restaurant, New Milton, and an informal vote of thanks to the Directors was moved by Mr. Arthur Wrigley on behalf of the President.

REFERENCES

Gardner, J. S., Keeping, H. and Monckton, H. W. 1888. The Barton and Upper Bagshot Formations. *Quart. Journ. Geol. Soc.*, 44, pp. 578–635.

Chandler, M. E. J. 1922. A recent Exposure of the "Marine Bed," Hordle, Hants. *Geol. Mag.*, 59, pp. 224–9.

Burton, E. St. John. 1929. The Horizons of Bryozoa (Polyzoa) in the Upper Eocene Beds of Hampshire. *Quart. Journ. Geol. Soc.*, 85, pp. 223–39.

Chatwin, C. P. 1936. *The Hampshire Basin and Adjoining Areas*, pp. 61–3.

Burton, E. St. John and Curry, D. 1937. Field Meeting at Barton, Hants. *Proc. Geol. Assoc.*, 48, pp. 374–8.

FIELD MEETING ON THE SOUTH DOWNS

Saturday, 11th June, 1949

Report by the Director : B. W. Sparks, B.A.

[*Received 7th July*, 1949]

THE party, comprising 30 members and friends, left Shoreham-by-Sea station and followed the minor road north along the ridge immediately east of the river Adur, the first halt being on the remnant of 180-foot platform at Mill Hill. Here the Director gave a general account of the denudation chronology of the South Downs, which have evolved predominantly under the influence of a series of negative movements of base-level. The highest levels, the mid-Tertiary peneplain and the early Pliocene marine bench, are represented in the area by summit-levels only, but clearer evidence of lower platforms was seen from this viewpoint and from others during the course of the day. From the same position other features of interest were seen, namely the heavily aggraded lower course of the Adur with an abandoned undercut cliff on the western side of Mill Hill, the Coastal Plain with its veneer of Pleistocene deposits and the abrupt southward termination of the South Downs. A second halt was made on the crest of the Downs immediately west of Beeding Hill to show the influence of structure on the topography of the low Weald, but, unfortunately, the view was somewhat obscured by haze.

After lunch, which was taken at Bramber, the party went down the western side of the Adur gap before turning sharply westwards to Annington Hill. From this spur, which preserves fragments of high terraces of the Adur, the evidence for the hypothesis that the Adur has migrated eastwards since the early Pliocene was discussed. The party then crossed the Downs to the col north of Cissbury Ring, whence four fragments of the dissected secondary escarpment are visible, namely Steep Down, Cissbury Ring, Church Hill and Blackpatch Hill. The Director emphasised the problems involved both in determining the horizons of the lithological differences within the Upper Chalk which cause the escarpment and in deducing the nature of the drainage pattern which has etched out the escarpment. At the same point, the different views on the origin of dry Chalk valleys were summarised and reference made to various features of these valleys observed during the course of the day.

In reply to a vote of thanks made by Mr. E. C. Martin, the Director thanked Mr. A. H. Ridout for acting as Field Meeting Secretary. Afterwards the party went to Findon for tea, most of the members ultimately catching the 5.35 p.m. train from Worthing Central station to Victoria.

For a fuller discussion of the features seen during the Field Meeting reference should be made to a paper by the Director on "The Denudation Chronology of the Dip-Slope of the South Downs," (*Proc. Geol. Assoc.*, 60, 1949, pp. 165–215) and to various papers quoted therein.

SOME FEATURES IN THE STRUCTURE AND GEOMORPHOLOGY OF THE COUNTRY AROUND FERNHURST, SUSSEX

By S. W. WOOLDRIDGE, D.Sc., F.R.G.S.

(*Weald Research Committee Report No.* 41)

[*Read* 10*th June*, 1949]
[*Received* 29*th June*, 1949]

CONTENTS

PAGE
Introduction 165
The Weald Clay 168
Dislocations of the Hythe Beds 177
The Date of the "Mass-Movements" 185
Conclusions 186
References 187
Discussion 187

ABSTRACT : The paper describes the structure of a part of the Western Weald. The work is based on 6-inch mapping of the base of the Hythe Beds and of a distinctive group of red clays some 400 feet from the top of that formation. It renders clear the character of the folding in this part of the Weald and throws light on the superficial "mass-movements", simulating faulting, which have affected the escarpment of the Hythe Beds. These movements are regarded as related to the widespread rubble drift occurring on hill-tops at about 300 feet on the low ground of the Weald Clay. An early Pleistocene age is tentatively ascribed to them.

INTRODUCTION

THE Lower Greensand heights of the Western Weald afford some of the most striking of the scenery of that classic area. The dominant feature is the escarpment of the Hythe Beds which locally reaches an almost precipitous steepness with its culminating points, Blackdown (918 feet), and Hindhead (890 feet), rising about 700 feet above the plain of the Weald Clay. The Hythe Beds here reach a thickness of 250–300 feet and rest upon the thick undermass of the Weald Clay more than 1000 feet in thickness. The thin intervening formation, the Atherfield Clay, is difficult to trace in many places and for physiographic purposes may be regarded as the top of the Weald Clay. To the juxtaposition of this great clay formation and the overlying Hythe Beds, the chief scenic contrasts of the region are due.

References to the area in Topley's Geology of the Weald are very few and brief and at the time he wrote contoured maps for much of the area, and accurate summit elevations for the hills, were not available. Most of the ground here treated lies on Sheet 300 (New

Series), not yet revised by H.M. Geological Survey. The old hand-coloured maps (Sheets 8 and 9) sufficiently indicate the main features of structure, but the country is complex in detail, much dissected, and heavily wooded, and it presents a number of features of special interest which it is the aim of the paper to elucidate. The writer began work in the area with a view to interpreting its physiographic features, but it soon appeared that a much more accurate picture of the structure was required for this purpose. The ground has accordingly been re-surveyed on the 6-inch scale with particular reference to the base of the Hythe Beds and of an important datum horizon in the Weald Clay, the top of the highest group of red clays, which immediately underlie a strong development of sandstone.

The area is traversed by two of the group of parallel anticlines which constitute the Wealden structure. On the north is the Hindhead anticline passing beneath the summit of Hindhead and traceable, as noted by Topley, for some distance eastwards in the Weald Clay. This is a comparatively feeble flexure with an amplitude of little more than 100–150 feet. To the south, beyond the shallow intervening syncline of the Haslemere area, is the better marked Fernhurst anticline, traceable westwards from near Fernhurst to Harting Combe and beyond. Its crest has been breached and a long tongue of Weald Clay opened up along its axis. Topley was disposed to identify this axis with the central or Crowborough axis of the Weald, but though it is traceable for some distance east into the Weald Clay, the Old Series maps do not enable us to locate with accuracy its eastern " closing " nor link it directly with the country east of Horsham. The form of the Hythe Beds outcrop around the Fernhurst vale, and particularly the disposition of the drainage, suggests that, even here, there may be two independent domes, slightly out of alignment, the one reaching its culminating point near Milland and the other near or east of Fernhurst.

A contoured map of the area makes the broad features almost as apparent as the old geological map itself and further demonstrates the sharp westerly pitch on both the Hindhead and Fernhurst axes. The regularity of the dip-slopes south of the Fernhurst axis and north of Hindhead further suggests that these are close approximations to true structural surfaces, the overlying Bargate and Sandgate Beds having been stripped evenly from above the Hythe sandstones with their reinforcements of chert. This may be the case locally, but it is not generally true ; the readiest structural datum plane is evidently the base of the Hythe Beds. This proves unexpectedly difficult to map with accuracy. Though the oncoming of the Hythe Beds above the clay is generally marked by a strong feature and a spring line, precision is difficult to attain. It is always possible to locate the Hythe base within 100 yards on the ground, but the slopes are so steep that this range of error is material in terms of elevation. The most casual scrutiny shows that downwash or " run of the hill " is strongly developed and landslipping is ubiquitous. Moreover the conditions are clearly favourable to what has recently been termed "cambering". It is not possible to demonstrate this so fully as in the now classic ground of the Northamptonshire Ironstone field, but it can be proved locally, as near Woolhouse Farm (861249)[1], east of Lodsworth, where the Hythe Beds descend sharply from River into the water-gap of the little River Lod ; and probably also along the eastern side of Hindhead (p. 181).

In speaking thus of the disturbances of the Hythe Beds we are making exception of certain major dislocations treated below (p. 177). Though they may be genetically related to the minor forms of mass-movement which confuse the junctions they are of an altogether different order and simulate the effects of faulting. Ignoring these for the moment, careful mapping combined with the evidence of well records reveals the following facts concerning the attitude of the base of the Hythe Beds.

At the southern foot of Blackdown, the base is well above 600 feet, but it falls steadily westwards along the northern side of the Fernhurst anticline, lying above 500 feet at Fridays Hill and at or below that level at the foot of Marley Heights. Beyond, the scarp is broken by the broad flat-floored combe south of Linchmere ; at its head, at Linchmere Marsh, the base is at about 400 feet. It keeps close to this level south-westwards to the foot of Iron Hill ; here evidently the face of the escarpment is parallel with the strike. Beyond, past Milland to Harting Combe, it is never far from 300 feet, which elevation it maintains along the " south crop " as far as Dunner Hill. The continuity of the southern escarpment is here broken by the northward projecting promontory of Telegraph Hill, on the northern face of which the base is *circa* 550 feet. It is about 450 feet at Bexleyhill, beyond which, complicated by land-slipping, it swings back and down into the Lodsworth gap. Beyond, it climbs again to about 340 feet below the Monument in Petworth Park, descending again eastwards into the Petworth gap.

The southern dip-slope of the Fernhurst anticline is of very regular form. Wells north-east of Rogate, at Stubbs Hill, Midhurst sanatorium, Midhurst water-works and Tillington provide data for stratum contours in the base. Along a line north of Midhurst there is a sharp subsidiary anticlinal roll which reverses the regional dip of the Sandgate Beds north of Ambersham Bridge and elsewhere ; the wide expansion of the Sandgate outcrop east of Midhurst is brought about by this fold.

North of the northern escarpment the structure is less simple. On the eastern side of Blackdown the base retains its high level (*circa* 650 feet) as far north as Aldworth House. Borings at Chase Farm, Dene End and Upperfold, taken with the evidence of outcrop, confirm the northerly swing of the stratum contours between Marley Heights and Blackdown and fix the approximate position of the axis of the Haslemere syncline, well south of the present river valley at Haslemere. On the far side of this valley the base climbs from about 500 feet at Haslemere High Street, and 400 feet near Shottermill, to the summit of Hindhead, where it probably just exceeds 600 feet, as indicated by two local wells and the spring line at the top of the Devil's Punch Bowl. The northward descent is at first gentle (about 2°), but on approaching Thursley it steepens to about 4°, the beds being affected by a sharp flexure traceable eastwards along the line of the east–west escarpment past Hambledon to Hascombe Beeches. On this line dips up to 18° are recorded, though evidence from wells shows that the belt of steep inclination is a narrow one.

---

[1] This and other references are in terms of the National Grid now used on the Ordnance Survey Maps and shown in Fig. 1.

These facts confirm, and give an outline of the quantitative basis for, the brief description of the local structure given by Topley. They leave several problems unanswered, however. The chief of these is the cause of the rectangular turn of the escarpment at Blackdown. From here it maintains a roughly north–south line for five miles until at Rutton Hill it again turns eastwards towards Hascombe. This line crosses the axis of the Haslemere syncline and the Hindhead anticline. Along it there are evident signs of dislocation, either large-scale landslipping or more fundamental movements akin to faulting. The Blackdown–Hindhead angle, if we may so term it, is the evident analogue of the similar angles at Hascombe and east of Leith Hill, though on an even larger scale. In both these other cases it has been proposed to explain the form of the outcrop by invoking a north–south monoclinal flexure "throwing" west [**1**]*. This is open to the obvious objection that no such monoclines can be shown to affect the adjacent Chalk. Moreover, the effect might be alternatively explained by a suitable disposition of periclines *en échelon*, which clearly avails to explain the chief rectangular bends in the South Downs escarpment and the familiar example in the Isle of Wight. The Blackdown–Hindhead angle is in some respects a more favourable instance for study than the other Wealden examples, yet the study of the form of the base of the Hythe Beds fails to throw any clear light on the matter and certainly cannot discriminate between the alternative hypotheses of north–south monoclinal bending and east–west folding of the usual "echeloned" Wealden type. It was this consideration which directed the writer's efforts to the sub-division of the Weald Clay.

THE WEALD CLAY

There is no reason to doubt that the Weald Clay exceeds 1000 feet in thickness in this area; the Henfield boring 12 miles beyond its eastern boundary recorded 1300 feet, while the Dunsfold boring, within the area mapped, records 900 feet and starts at a point well below the top. Only the topmost part, 5–600 feet thick, is exposed in the area and there is little published information about it. Topley's account mentions very few of the subordinate sandstone outcrops in this part of the Weald and the work of P. J. Martin hardly extended so far. The present writer, following beginnings made by I. C. Collins and J. F. N. Green near Fernhurst, has been attempting at intervals for nearly 20 years to subdivide the Weald Clay of the district. Deeply cut stream-courses near Fernhurst give good sections in a sandstone horizon of which the base is some 400 feet below that of the Hythe Beds. A short distance below it bright crimson clays, reminiscent of parts of the Keuper Marl or of the Reading Beds, invariably make their appearance. A brief note on the sandstone at Fernhurst was included by J. F. N. Green in the General Report of the Weald Research Committee in 1928 [2]. Ten years later the present writer stated the succession in more detail, attempting to distinguish two sandstone bands, the lower resting on the red clay [3].

---

* For list of References see p. 187.

At first it seemed probable that the remarkable dissection of the district by the headstreams of the Arun system would offer a ready means of tracing this or other sandstones in the area. But the miniature gorges were for the most part densely and almost impenetrably wooded, their steep sides have slumped badly and their floors are covered with thick alluvia. Satisfactory outcrops were thus few and far between. The tracing of the sandstone over the intervening country proved even more difficult. Locally it makes a distinct minor escarpment, but this is of very variable prominence and the overlying clay often completely covers the dip-slope and creeps down the scarp-face. Again one quickly realises that the alleged drift-free character of the Weald is often illusory ; there are wide tracts of river-gravel and scarp-drift and an extensive blanket of redeposited Weald Clay which may well be a species of loess. In the result it for long proved an arduous and unrewarding task to trace the sandstone outcrops with any precision. The position has been materially eased, however, in recent years, by the ploughing of much of the pasture land and the clearing of woodland. The country is now much more accessible. The passage of the years has also brought to hand a long series of records of temporary sections in road widening, field drainage and the like. Of equal importance in finishing the map has been the indication given by the work of the Rev. J. W. Reeves for the D'Arcy Exploration Company near Henfield [4]. Confronted with a similar, perhaps identical, succession in the upper beds of the Weald Clay, he showed the advantage of treating the top of the red clays as the datum for mapping. The same method avails well in the Haslemere country and solves a number of difficulties. Further bands of sandstone occur below or within the red clay division as well as above the main Fernhurst horizon, and in the writer's first efforts at mapping the beds the attempt was made to group these with the Fernhurst sandstone in a " zone of sandy intercalations." This method was used by G. W. Lamplugh over a small area on the Chichester sheet, but extended westwards it proved to give very indefinite boundaries, both upper and lower, and failed adequately to bring out the structure of the country. Here, therefore, we follow the nomenclature instituted and recently published by Reeves, recognising an upper or " yellow division " with the Fernhurst Sand at its base, with the main mass of red clay as the mapped index horizon below it. It is impossible here to record the whole of the local detail on which the mapping is based, but reference is made to the more important locations.

(a) The Fernhurst Area

We may first establish the succession as displayed in the core of the Fernhurst anticline near Fernhurst. On the north side of the anticline, the top of the sandstone series beneath black shaley clays is revealed in the streambank east of Sopers Farm (905288) at an elevation of 260–270 feet O.D. It is traceable thence for some distance southwards down the stream gully, showing a thickness of at least 20–30 feet. Three hundred yards south of the first point, where the footpath eastwards from the village crosses the stream (905286), there is a good sandstone section in the gully side. The ground level is at about 275 feet and the floor of the stream trench below 250 feet. Lower down the valley, and in tributary gullies, the underlying red clay appears south of Fernhurst village. The sandstone caps the long spur on the eastern side of the valley here, and the red clay is exposed beneath it at above 200 feet on the western and also on the eastern side of the spur. It was seen too in the pipe-line trench southwards along the road from Fernhurst Green and also in Homeland Copse, and on the steep slope west of Verdley Place. This last estate was taken over as a research station by Plant Protection Limited in 1946 and Mr. Basil Furneaux conducted a soil reconnaissance of which the results have been made available to the writer. It amply confirmed the red clay-sandstone boundary as here drawn. Locally, as around Hurstfold Farm (909268), a thin cover of stony drift covers the clay, which was exposed beneath it in the excavation for an irrigation tank for the glass-houses. Farther south, where the River Lod cuts a deep trench, red clay is seen in the valley-sides at Surney Hatch and it makes a good junction at about 150 feet O.D. with overlying sand or sandstone on the south bank near Surney Farm, where the sandy outcrop has been laid out in orchard lands (Fig. 1).

These notes concern the area east of the main road southwards from Fernhurst village. During the last six months this road has been widened, affording good confirmatory sections. Immediately south of the village the sandstone was covered by rubble-drift set in a

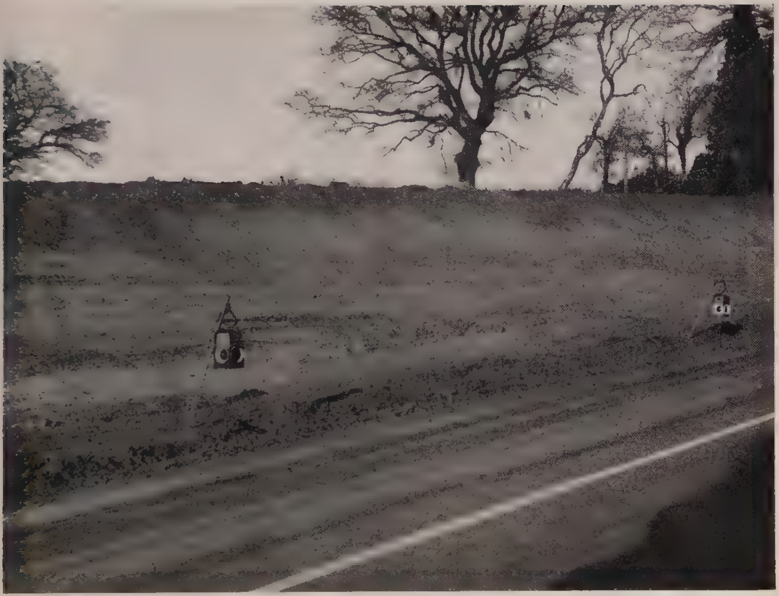


Photo : F. Goldring.

Fernhurst Sandstone dipping northward in road cutting south of village.

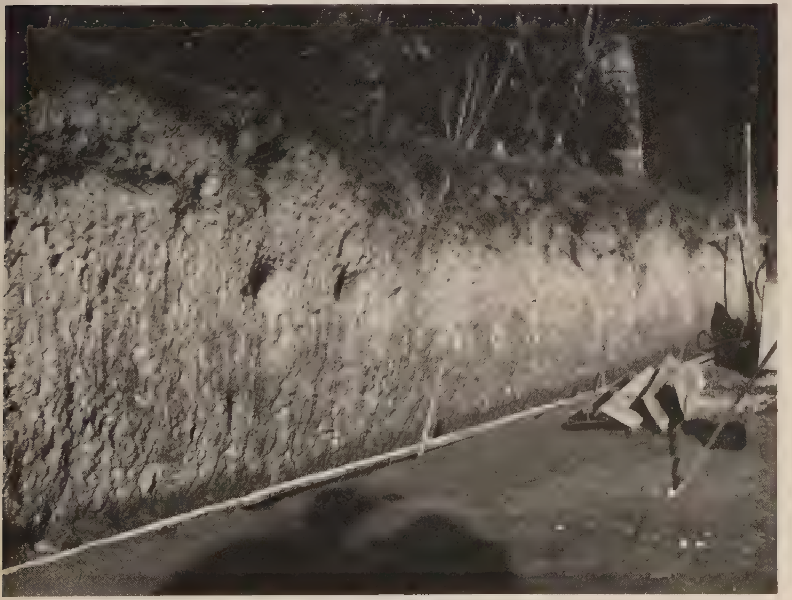


Photo : F. Goldring.

Rubble drift in road cutting south of Fernhurst cross-roads.

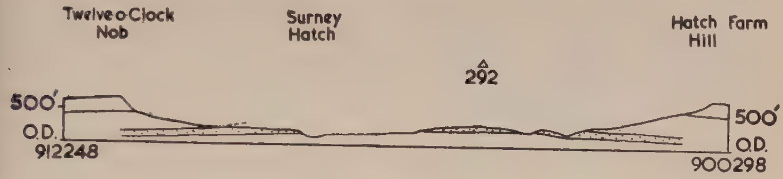


FIG. 1.—Section across the Fernhurst anticline east of Fernhurst, showing base of Hythe Beds and Fernhurst sandstone.

clay base and evidently derived from the slope above (Plate 5). On the western side of the road north of Woodfold (about 895281) the sandstone was well exposed dipping northwards. The red clay comes on southwards and approaches very close to the base of the sandstone, with a small thickness of brownish or red-mottled clay intervening. From the point noted above red clay is traceable southwards to Cooks Bridge beneath a thin cover of surface wash.

West of the main road the conditions are different and in some respects obscure. The sandstone is well exposed in the steeply-cut gully north of Hawksfold Farm (888283),[1] beneath clay. The sandstone does not crop out in the ground immediately to the south, but appears to roll over the crest of the Fernhurst anticline without showing its base, and carrying a superficial cover of the upper or yellow clays. What we have taken as the top of the sandstone is seen in the stream bank about 200 yards south of Lower Hawksfold; here there is a little red clay above it. Southwards it emerges at the surface over a small area of former grassland, now ploughed, but its top is seen again below clay in the stream bank at the north-west of Turners Copse (886274) and at other points near by both to the east and the west. On this meridian, therefore, roughly the grid-line 89, the sandstone lies much lower than it does on or east of the main road and the red clay beneath it is nowhere seen, though it appears in Collier's Copse (892279) and in the floor of the main valley west of Cooks Bridge. South of the latter point the sandstone builds a considerable escarpment which however disappears quite suddenly westwards. These facts suggest that there is either a small dip fault or a relatively sharp acceleration of the westerly pitch of the main anticline along the line indicated on the map. I. C. Collins was led to a similar interpretation of the structure in his own work in the area. The relations of the sandstone east and west of the supposed fault are shown in Figs. 2 and 3.

These facts suffice to establish the local succession and structure though certain points of detail are still obscure. The crest of the anticline appears to be about half a mile south of Fernhurst village

---

[1] This is the only exposure in the area noted in Topley's *Weald* (p. 109) where Hawksfold is called Oxfield Farm under which name it appears on the Old Series map.

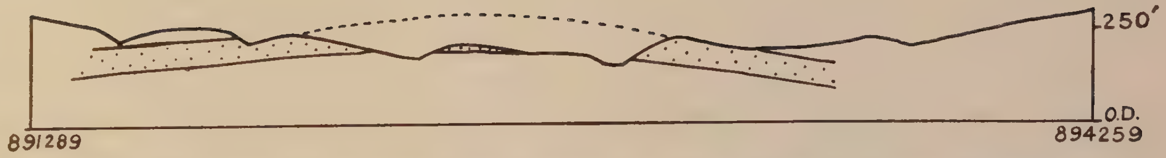


FIG. 2.—The relations of the Fernhurst Sandstone immediately west of the main road south of Fernhurst.

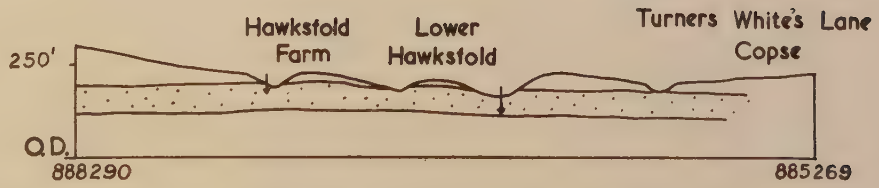


FIG. 3.—The relations of the Fernhurst Sandstone west of supposed fault.

near the east–west grid line 28. The long stream section east of the village would appear to demonstrate a thickness of some 50 feet in the generally sandy series unless, as is probable, there is local rolling of the beds or untraceable minor faulting increasing the apparent thickness. There appear to be two main sandstone courses within the Group, separated by finer grained clayey or silty beds and a small thickness of similar beds seems immediately to overlie the red clay.

(b) The Milland Area

The Fernhurst Sandstone and the underlying red clays reappear as an inlier three miles westwards. The higher ground between Telegraph Hill and Iron Hill which forms the transverse water-parting of the vale shows nothing but the "yellow series", but the red clay re-emerges around Milland Cross-roads (838270), where it is exposed in an old brickyard and was well seen in foundation trenches north-west of the Rising Sun Inn. The sandstone outcrop surrounds it and gives a zone of notably lighter soils amid the heavy clay land. The country here is flat and featureless and widely drift-covered with Hythe Beds rubble and alluvium, so that the lines are difficult to trace in detail. The chief importance of the records is that they confirm the existence of a smaller second culmination on the general anticlinal line, and, since the dip on the anticlinal flanks is more readily determined than at Fernhurst, they enable us to confirm with some precision the horizon of the red clay at about 400 feet beneath the base of the Hythe Beds.

(c) The Petworth Area

A third area in which the relations of the beds are well seen is around Stag Park Farm about 2½ miles north-north-west of Petworth. A small pit west of the main road (959255) shows the sandstone, while the underlying red clays are well seen in the southern part of the adjacent Colhook Brick and Tile Works. The sandstone forms a true escarpment projecting forward as a prominent bastion between the Petworth and Lodsworth valleys. Dissection of the dip-slope has opened up an irregular inlier in the red clay. On the face of the escarpment and below the top of the red clay a second sandstone occurs and has been worked south of Blackwool Farm ; it forms the surface over considerable areas in the country to the north.

The base of the upper sandstone, with the red clays beneath it, is traceable eastwards to Moor Farm (986237) and so on to the ground mapped by Lamplugh on the Chichester sheet. His " zone of sandy intercalations " includes both the upper and lower sandstones and the index horizon at the top of the red clay thus falls within his mapped outcrop. The line here adopted is also traceable westwards past Parkhurst Farm and Lickfold (localities mentioned by

Topley following Martin) and so to Surney Hatch (908266) where it links up with the line traced eastwards from the King's Arms Inn (Fig. 2).

(d) Lurgashall, Northchapel and Chiddingfold Areas

The red clay is readily traceable around Lurgashall and Northchapel. It occurs far up the stream trench south of Windfallwood Common (926278) at an elevation of above 200 feet. Some distance below its top here a distinctive horizon, with clay breccias and much lignite and carbonised wood, is seen. The sandstone is exposed south of Diddlesfold Manor Farm (948293), near Northchapel, and the underlying red clay was well seen in foundation trenches on the slope south of the church. On the lower ground east and north-east of Northchapel evidence is not so full and more of the land is in pasture. The " yellow series " occupies a broad zone to the north, marking the eastern continuation of the Haslemere syncline. The underlying red beds nowhere appear within this tract, though the sandstone is seen south of Fisher Street (*circa* 951309). Attention may be drawn to the ridge of high ground followed by the county boundary ; it presents something of the aspect of a southward facing escarpment such as is sometimes made by the sandstone feature. This is not its nature. Red clay appears in the road cutting at Whites Hill (968331) below the sandstone, here capping the ridge. Westward the sandstone descends from the summit, and east of Ramsnest Common (955330) it occurs at the northern foot of the ridge which is formed of the clay rising above it, protected by a capping of rubbly chert and sandstone drift (p. 185).

North of the county boundary ridge, the outcrop is notably sinuous in the Chiddingfold country. It shows the influence of the Hindhead anticline which raises the red clays almost to 250 feet at the brickworks north-west of Chiddingfold. But the country is deeply dissected by three northward flowing streams tributary to the Dunsfold branch of the Arun. The most westerly of these, close to the railway line, opens up a long narrow inlier of the red clay. The sandstone caps the eastern slope above Garsons Copse (*circa* 935359) and is seen also farther west in Pond Copse (924358). The valleys respectively east and west of the main road south of Chiddingfold offer obscure heavily wooded ground. No sign of the red clay has yet been found in the western valley ; the sides have been much subject to slipping. The eastern valley shows the normal sequence and beyond it the sandy beds cap the high ground around and south of Pickhurst, where they were probably laid under contribution for the medieval glass-making industry. The sandstone is also exposed farther south in the deep " ghyll " at Netherside (942341) but the valley does not expose the underlying beds.

North of Chiddingfold the beds become increasingly involved in the sharp flexure at or near the line of the Greensand escarpment

(p. 168) and the outcrop of the "yellow series" is relatively narrow. The sandstone is exposed in the road-cutting north of the Winterton Arms (964366); this is the exposure noted by Topley as "a little south of Hambledon Hurst". From here it may be traced westwards to Noddings Farm, south of Witley station and eastwards to Dunsfold.

This fairly detailed commentary on the Fernhurst Sandstone and the beds below it is necessary to make clear the basis of the map (Fig. 4) and to sustain the structural conclusions based upon it. Fig. 5 shows stratum contours for the top of the red clay deduced from its surface outcrops and from its assumed position 400 feet below the base of the Hythe Beds. This assumption might seem open to objection. It is only within the anticlinal vale at Fernhurst that any tolerably accurate estimate of its position can be made. If the upper or "yellow division" were subject to any marked variation

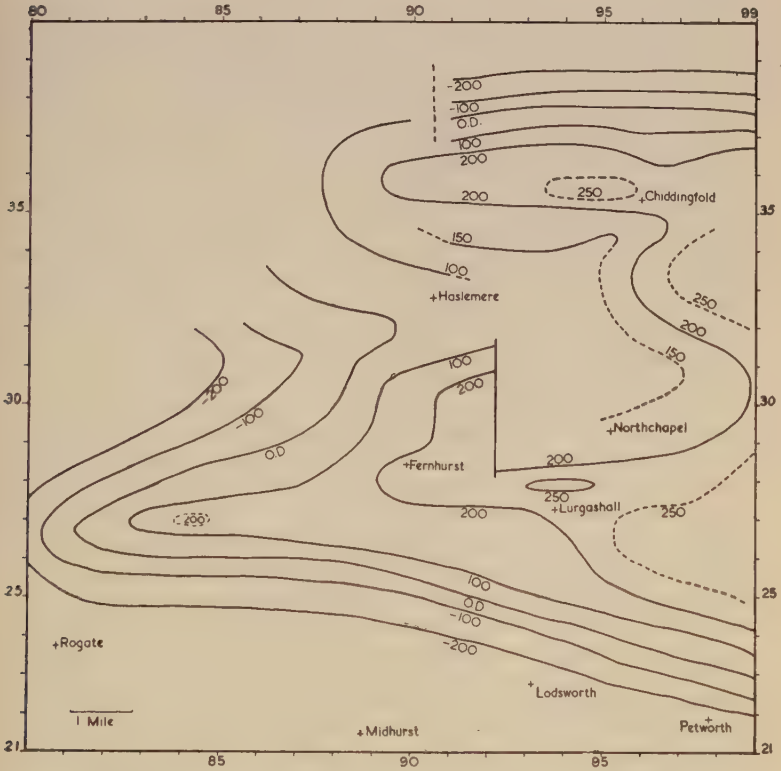


FIG. 5.—Map of stratum contours for the top of the red clay.

of thickness the assumption would prove false. It is therefore relevant to notice that Reeves obtains a comparable figure for the country around Henfield, 12 miles east of our eastern boundary [**4**]. Moreover a similar succession is traceable below the western part of the Leith Hill range. The sandstone occurs north of Ewhurst, with red clay below it, and is traceable eastwards as far as Losely. Here again the horizon of the top of the red clay appears to be about 400 feet down in the Weald Clay. There is reason to hope, therefore, that the stratum contours shown in Fig. 5 give a tolerably true indication of the structure of the area.

The main features brought out by the map are as follows. Five distinct periclinal culminations are indicated within the area. In the south-west is the small Milland dome, which fades eastwards and is replaced *en échelon*, with a northerly offset of about half a mile, by the Fernhurst pericline traceable eastwards to a point beyond Lurgashall and with its axis only about half a mile south of the summit of Blackdown. South-east of Lurgashall an independent fold sets in on a more southerly line. It is revealed by the high elevation reached by the top of the red clay north of Petworth and the axis trends roughly east–west through Balls Cross. These three periclinal features constitute the Fernhurst or Harting Combe "axis", continuing that of Winchester in the country farther west.

In the north of our area the form of the Hindhead fold is clearly shown. Judged by the position of the red clay west of Chiddingfold, it reaches its culmination hereabouts and is doubtless traceable for some distance farther east. But the disposition of the red clay south-east of Chiddingfold indicates the western pitching nose of another fold on a more southerly line, its axis trending from near Dyer's Cross eastwards towards Dunsfold. It will be noted that the relation of this fold to the Hindhead anticline closely simulates that of the Balls Cross to the Fernhurst fold.

Between the northern and southern anticlinal zones lies a synclinal area which shows greater complexity of form than might at first be suspected. In the west the Haslemere syncline, pitching westwards and with its axis trending west-south-west from Haslemere towards Liphook, intervenes between the Milland and Hindhead anticlines. In the east a similar syncline intervenes between the Balls Cross and Dyer's Cross folds. Its axis lies about a mile north of Northchapel and it pitches westward. Between the two is a species of structural plateau or terrace in the vicinity of Blackdown.

It will at once be seen that our structural map, through inevitable default of data, fails to elucidate the structure fully. It shows, however, clear evidence of an easterly descent of the beds east of Blackdown, however caused. The northward bend of the 100 feet and 200 feet stratum contours north of Fernhurst is well indicated by the disposition of the Hythe Beds and is, indeed, legible in the landscape in the relatively rapid descent of the Hythe Beds summits west of Blackdown (Blackdown 918 feet, Marley Heights 700 feet, Iron Hill 650 feet). Beneath Blackdown summit and for nearly a mile northwards the base of the Hythe Beds is at about 650 feet and the red clay datum horizon must therefore be assigned a level of 250 feet. East of Blackdown it nowhere attains this level. Between Northchapel and Blackdown summit it might attain 200 feet, or nearly so, which would imply an eastward depression of level of 50 feet. Northwards we have no means of placing the position of the datum horizon accurately, but it is evident that it might well descend to 100 feet or below, implying dislocation of 100 feet or more. It is important to notice that we are, for the moment, disregarding the long down-slipped or down-faulted mass of Hythe Beds which lies along the eastern side of Blackdown. Since its structural relations are problematical, to introduce it here would be to beg the question ; it is discussed below. Apart altogether from the evidence of this mass, it is clear that there is no suggestion along the north–south Blackdown line of a monocline " throwing " westwards. There is, on the contrary, clear indication of monoclinal flexuring and—or—faulting along this line, depressing the beds to the east. It is to be noted, however, that the top of the red clays in the latitude of Lurgashall shows no evidence of such disjunction ; if a fault exists farther north, it dies out southwards. It is also clear that the " Blackdown angle " cannot be explained by the accommodation of the outcrop to anticlines *en échelon*. If the position of the syncline north of Northchapel had been occupied by an anticline, this explanation would avail. The presence of a syncline in this position demonstrates the presence of some species of north–south disjunction of the structure.

DISLOCATIONS OF THE HYTHE BEDS

We turn now to consider some of the major dislocations, whether by mass-movement or otherwise, which complicate the margin of the outcrop of the Hythe Beds.

(a) Telegraph Hill

The southern escarpment culminates at Telegraph Hill (678 feet) where it projects northwards, bastion-like, nearly a mile in advance of the general line. There is clear evidence of major land-slipping on both the west and the east sides of this promontory. On the west lies the spur known as Older Hill, its summit marked by a Trigonometrical Station (868264) at a height of 602 feet O.D. It is this under-feature which gives the conspicuous terraced profile to the western side of Telegraph Hill and it is readily demonstrated that the lower mass is compounded of a series of slipped slices descending step-wise towards the low ground at Stedham Marsh.

The main or dorsal dislocation can be traced from the spring

(868266) southwards close to the deeply sunken track which ascends towards the Trigonometrical station. Along this track the displaced Hythe Beds strike roughly north–south and dip at 30–40° eastwards —i.e. towards the main slope above. The slip thus reveals the well-known and characteristic rotational structure associated with slip-planes concave upwards. South-westwards from its summit the crest-line of Older Hill descends in three marked steps corresponding, it is thought, to three further slips of relatively small magnitude. The total displacement achieved by the four parallel slips is not easy to gauge, since the height of the base of the Hythe Beds on the main mass of Telegraph Hill is difficult to determine. There is no well-marked basal feature or spring line in West Copse (*circa* 872266), downwash from the steep slope above, and possibly cambering, having obscured the true junction. We may probably place the latter at about 550 feet. The base of the slipped mass at its northern end is below 500 feet (say 460–470 feet) while its frontal edge above the Plough Inn, is little above 400 feet. Reckoning in terms of surface levels the dorsal displacement would be some 75 feet (the difference in summit levels between Telegraph and Older Hill). It is evident, in any case, that the general base of the slipped mass is inclined forwards at an angle of perhaps 2–3°.

Immediately south of Older Hill is a deep combe draining westwards. Although thick vegetation makes it impossible actually to trace the slip-surfaces across the combe, there is little doubt that they so continue, for the ground beyond shows typical slip-topography, and the succession of slipped masses seems to correspond across the combe. Either the first and second, or the second and third of the Older Hill slips (numbering outwards from the back) can be identified, and one or other of them makes a further feature just above the 500 foot contour west of Pigeonhill Farm (869255). There is thus a strong suggestion that the combe has been wholly eroded, or at least greatly widened and deepened, since the episode of slipping. If this is so, the slipping is evidently no recent phenomenon. The fashion in which the northern end of the slip projects beyond the main escarpment also suggests an antiquity sufficiently great to permit appreciable recession of the main escarpment since the slipping occurred.

Viewed from the north the composite slipped mass of Older Hill appears as a barrier appreciably narrowing the gap at Stedham Marsh. At first sight it is easily overlooked that this is no longer a functioning water-gap carrying drainage from the Vale of Fernhurst. The Hammer stream draining the gap to the west has quite recently inserted a tributary across the mouth of the gap at Stedham Marsh, eroded by the unnamed stream draining southwards past Wispers. The Hammer stream enjoys, in any case, a slight advantage in structural position because of the " Milland dome " but it seems likely that the narrowing or partial damming of the eastern gap

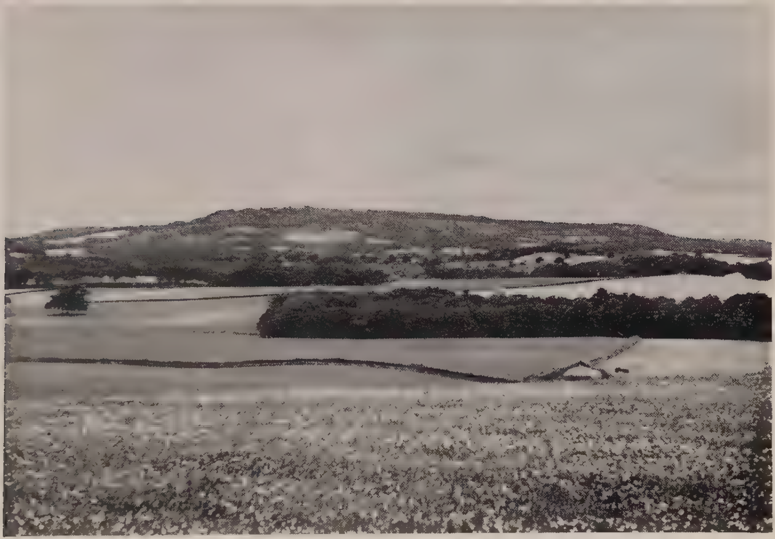


Photo : F. Goldring.

Blackdown, from near Stagpark Farm.

Photo : F. Goldring.

Western closure of Fernhurst anticline and wind gap at Redford, from Older Hill.

[*To face p.* 178.

deprived its tenant of so much vigour as to cause, or at least to hasten, the capture of its headstream by its successful rival (Plate 6).

The eastern side of the Telegraph Hill bastion shows similar landslip features. The present main road at Henley Hill, reconstructed early in the nineteenth century in a wide loop to avoid the steep direct climb through Henley village, was cut across landslipped ground. Structureless rock-rubble is exposed in a small roadside pit (892259) at a height of about 450 feet O.D. on the scarp-face, and the tilting and disruption of the beds is evident enough in the great bank above the road. Below, the lower sands of the Hythe Beds descend almost to the 300-foot contour, at least 150 feet below their true position. The sandy knoll at Birchill Copse (884266) marks a frontal bastion of the slip partly detached from the main mass by circum-denudation. Supplementary evidence of the reality of the slipping and its multiple nature is seen along the crest of the escarpment, north of the Trigonometrical Point 548 (888257), where several parallel scars mark the " back-walls " of slipped slices. These may be traced round towards the north-east corner of the Telegraph Hill promontory where an ear-like extension occurs, comparable in form and position with Older Hill, and forming a spur above Upper Lodge. The ground is heavily wooded here and difficult to study in detail but the symptoms of slipping are manifest.

On both flanks of the Telegraph Hill mass the slipping is curvilinear in plan and it is clear that the promontory has developed by a species of " biscuit-cutting " or back-to-back scalloping action wherein slices of Hythe Beds, their original base at the top of a considerable glacis of Weald Clay, have slumped in stepped rotational slips.

(b) Marley Heights

On the northern side of the Vale of Fernhurst slipping of the type described is evident on the western slopes of Marley Heights. Here some three or four slip-scars can be traced, none of them involving any large displacement. At a lower level is the outlier of Hythe Beds forming Greenhill (883294). The base of the Hythe Beds is here at least 50 feet below its position on the main escarpment. This might well be due to cambering, but though it is impossible to locate an actual slip-plane in the clay-floored col between outlier and escarpment, slipping, on the whole, seems the preferable hypothesis. A small exposure on the south side of the hill indicated that the beds there were not *in situ* ; nothing was seen but a fine-grained rock rubble like that exposed at Henley Hill. If the mass be interpreted as slipped there is again impressive evidence of the ancient date of the slipping as measured by the magnitude of subsequent erosion. The small neighbouring outlier to the east (891292) may once have been part of the same slipped mass.

(c) Leggatt Hill

Slipping with a curvilinear " back " has also affected the Hythe Beds east of Bexley Hill, where they descend into the Lodsworth gap at Leggatt Hill. The ground is thickly wooded and exposures are lacking, but drainage trenches north of Smithbrook showed that the beds were not *in situ*, but a structureless rock-rubble set in sand ; the mass as a whole is at least 50 feet below its true position. The Smithbrook valley may well have here initiated at the back of the slip and shows the process of dissection, leading to separation from the main mass, in a relatively early stage. On the opposite side of the Lodsworth gap, the only other place in the area beside Leggatt Hill where the base of the Hythe Beds descends below 250 feet, there is no sign of slipping, but clear evidence of pronounced cambering.

(d) Hindhead

On the eastern side of Hindhead, there is much similar evidence of " mass-movement " though the details at present remain obscure. The best general purview of the ground is obtained from Gibbet Hill. Immediately below and east of the summit is a col just above 800 feet (*circa* 901358) beyond which a sharp knoll rises, presenting the aspect of a slipped or downfaulted mass. Confirmation of any tilting of the beds is lacking in the absence of adequate exposures. Farther east lies the Inval ridge separated from the main mass of Hindhead by the deep and notably straight valley descending towards Haslemere past Great Stoatley. The form of the ground as a whole strongly suggests slipping or faulting. A line of dislocation may presumably be inferred trending south-westwards from the col below Gibbet Hill along, or parallel with, the scarp-like western side of the Stoatley valley. The summit of the Inval ridge (852 feet) is lower, but not much lower, than the main mass of Hindhead Common. If it marks a dislocated mass, it must be " backed " by another line of dislocation which cannot at present be precisely located. It is certain, however, that the Inval mass as a whole is not far below its true position, for a well at Keffolds gives the base of the Hythe Beds at 559 feet ; it cannot be much higher than this beneath the main mass.

When we turn northwards from Gibbet Hill to the broken ground about Boundless Copse (*circa* 901364) and the combe south of High Button, more definite evidence is available. A dislocation which seems to continue that passing through the col at Gibbet Hill can be located fairly accurately by the close juxtaposition of sand and clay in the vicinity of the point 903361.

The local boundary of the Hythe Beds around the Inval ridge can be traced from near High Button to the railway cutting at Grayswood Common. It is not very clearly marked and nowhere departs far from a level of 500 feet. In the northern part of the outcrop it is thus as much as 100 feet below its inferred structual position of 600 feet (p. 168) and an eastward or outward inclination of the base is apparent in relation to the well at Keffolds. This attitude is consistent with multiple slipping or " slumping " but it might be explained equally well in terms of "cambering". Since any dislocation appears to be on a relatively minor scale it seems necessary in any case to invoke the co-operation of cambering to explain the depression of the base of the Hythe Beds.

Very similar relations are found in the mass of Hythe Beds south of Grayswood. Seen from Gibbet Hill this mass might appear to mark a separate "slip", but that is not its nature. Its core certainly comprises Hythe Beds *in situ.* There is evidence of small-scale rotational slipping on its western side near the point 914343. The eastern side shows ample evidence of a "depressed base", and three small outliers are very reminiscent of those associated with dissected " cambers " in the Midlands. There would, indeed, be little cause to suspect dislocation in the ground immediately north of Haslemere if it were not for Drew's record [6] of the strange disturbance in the valley through which the railway runs. This is shown on the Old Series Map (Sheet 8) as a fault bounding the Grayswood mass, with downthrow to the east, and dying out westwards near Haslemere station.

This presentation does not entirely agree with Drew's description ; he mentions the presence of Weald Clay west of the fault, but the map shows Atherfield Clay only. The latter dipped at an angle of 50° to the west or north-west, and a dip of 44° in the same direction is recorded in the Hythe Beds on the western side of the cutting. These high inclinations were probably regarded by Drew as marking "terminal curvature", near the fault, but the observations taken as a whole are very suggestive of rotational slipping, though there is little or no suggestion of such in the form of the ground. It is at least clear that no large disjunction of level occurs, and without the evidence of the cutting (now completely overgrown) the disturbance would hardly be suspected. A further suggestive point is J. W. Salter's record of a sharp junction between dark blue Weald Clay and brown Atherfield Clay in the cutting [7]. No such sharp junction appeared in the Shottermill brickyard less than two miles away [8], and one is led to speculate on the possibility that what Salter saw was a "mechanical junction". There is the further difficulty that the high dips are recorded west of the mapped dislocation and not therefore in the supposedly " slipped " mass, though an *easterly* dip of 60° is recorded on the south side of the railway at a point some distance east of the station. There is thus ample evidence of disturbance of some kind but since no new or confirmatory evidence is now obtainable here, the " fault " is not shown as such on the map (Fig. 4). It appears very possible that the disturbance as a whole is an example of "valley-floor bulging".

A last point and one perhaps of considerable significance may be made concerning the structure of the eastern side of Hindhead. Little more than a mile north of Gibbet Hill, the " Hascombe–Hambledon " escarpment of the Hythe Beds is separated from the northern flank of Hindhead by a minor water-gap. On the eastern side of the gap, the escarpment attains an elevation of some 525 feet. West of the gap on the same line the ground exceeds 600 feet in elevation. One may say, therefore, that the generalised surface contours drawn on the dip-slope of the Hythe Beds are here disjointed along a north–south line in such fashion as to suggest the influence of a slight fault or monocline throwing eastwards. We have, it is true, no adequate evidence of the altitude of the base of the Hythe Beds across this line and the evidence of surface levels may well appear ambiguous or indecisive. It is at least clear, however, that if there is " disjunction " of the Hythe Beds here, with easterly inclination or downthrow, it cannot be explained by any species of slipping ; it would quite evidently be a " primary " structural effect. It occurs in a belt which, if projected southwards, would include the ground below Gibbet Hill. Such a structure would evidently predispose towards slipping or cambering here, and the significance of this observation will appear when we come to deal with the Blackdown area.

(e) Blackdown

The eastern side of Blackdown presents us with a much more strongly marked example of the disjunction of the base of the Hythe Beds, due either to land-slipping or to faulting. F. Drew detected signs of disturbance along this line in the course of the original Survey and interpreted them in terms of faulting. Topley, quoting from his notes, speaks of the fault " which runs in a southerly direction from Grayswood, where it is an upthrow on the east . . . but at the other end, on the contrary the downthrow is to the east, the evidence being the break in the line of springs which marks the bottom of the sand " [**6**]. The two spring lines are, in fact, well seen near Upper Roundhurst (927304), where the upper is at about 650 feet O.D. and the lower at 450 feet. The old map also shows a short fault farther south at Telegraph Cottage (924291). Mapping on a 6-inch scale shows that we are dealing not with two dislocations but with one, continuous for a distance of about two miles. There are in fact both an upper and a lower basal boundary for the Hythe Beds to be traced east of Blackdown. Immediately south of the summit a well reveals the base at 640 feet O.D. and the upper boundary keeps at or about this level along the eastern side of the mass as far as Aldworth House (925308). As a mapped line it is discontinuous, since the down-slipped or down-faulted mass rises above it or is at least flush with it at intervals. Elsewhere, at the head of the embayments in the scarp, as above Upper Roundhurst, and in

Abesters Copse, its position can be determined. The lower line, nowhere far from 450 feet O.D., can be traced continuously from below Telegraph Cottage northwards to a point below Aldworth, where a well at " The Pavilion " fixes the base as at 457 feet. Drew carried the fault east of Aldworth and terminated it there. In fact it seems to run behind (i.e. west of) the summit of the hill at Aldworth House ; this forms a spur some 50 feet lower than the main Blackdown plateau to the west of it, and the dislocation seems to pass through the high col which separates them and to follow the line of the valley down past Owlden (925313). Here a " gulf " of Weald Clay has been opened up by erosion between the main Hythe escarpment ranging north-westwards to Haste Hill and the spur of Hythe Beds at High Barn Farm (922319). The latter represents the " downfaulted mass " and the dislocation appears to follow a curving line along its western side. Beyond the northern end of the High Barn spur, it may trend northward to the col west of Lythe Hill, as supposed by Drew ; a small outlier of Hythe Beds lies on the eastern side of the line here but its base is hardly more than 50 feet below that of the main mass at Haste Hill. The dislocation evidently dies out northwards and there is at present no clear evidence of its continuation near Grayswood as supposed by Drew.

The Blackdown dislocation thus involves a strip of Hythe Beds two miles long and from a quarter to half a mile wide. At its southern end the displacement amounts to 200 feet, but north of Aldworth it may be 100 feet or less.

It will be recalled that similar phenomena have been described elsewhere in the Weald in recent years, as at Bower Hill, Nutfield [**9**] and Tilburstow Hill [**10**] and that different interpretations, based upon faulting and land-slipping respectively, have been offered. The Blackdown example is of high interest in that it affords a nicely balanced choice between these alternatives.

It would evidently be wholly perverse lightly to reject the hypothesis of faulting here, for even if there were no immediate evidence of dislocation the general structure requires some depression of the beds on the eastern side of the "Blackdown line". To this is added the obvious fact that the dislocated mass is on a substantially larger scale than the undoubted "rotational slips" at Telegraph Hill and elsewhere, and it fails to show the characteristic curvilinear "back". The rectilineal character of the fracture might indeed be urged as strong presumptive evidence of true faulting. But there are equally cogent arguments against this interpretation ; they may be summarised as follows :

(i) At the southern end of the mass, below Telegraph Cottage, the structure as exposed in the road cutting is quite evidently a " rotational slip " with back-tilting at an angle of about 40°.

(ii) At this end of the mass the " throw " (about 200 feet), is much greater than can be made reasonably consistent with the general structure. The top of the Fernhurst sand crops out little more than half a mile east of Telegraph Cottage at about 250 feet O.D. This is but slightly lower than we should expect it if there were no dislocation at all. A fault with a throw of 50 feet would be consistent with the outcrop, but a throw of 200 feet cannot be accommodated without an appreciable inward dip of the Weald Clay towards the fault plane of which there is at present no evidence. We must note, however, that we cannot apply this argument farther north ; here there is nothing to show that the top of the red clay may not be underground at, say, 50 feet O.D. in which case a full 200 feet of throw could be credited to the supposed fault.

(iii) The supposed line of faulting is not demonstrable in the Weald Clay country south of Blackdown (p. 177). This proves, at least, that any fault dies out quickly southwards and it might therefore seem a plausible view that its throw increased northwards. But, in fact, as far north as Roundhurst this is not the case. The base of the dislocated mass remains close to 450 feet and the throw must be roughly 200 feet.

(iv) A point very favourable to the hypothesis of slipping is the curved line of the dislocation, in plan, along the western side of the High Barn spur. This is evidently consistent with a gentle, rather than a steep, inclination.

(v) It would be anomalous, if not entirely inexplicable, if a "tectonic fault", dating presumably from Mid-Tertiary times, had so direct a topographic expression as the Blackdown dislocation. The original fault-scarp would have been obliterated in the ensuing peneplanation, and it is difficult to see any reason for its " reincarnation " as a fault-line scarp. There is the further difficulty that, interpreted as a simple fault, the dislocation at Aldworth implies that there is a thickness of some 350 feet of Lower Greensand on the downthrow side. This considerably exceeds the greatest recorded thickness of the Hythe Beds in the district, and the overlying Bargate Beds might be expected to follow. They are, in fact, absent.

There are, thus, very good reasons for regarding the dislocated mass as a " rotational slip " ; the whole of its character and relations, excepting only its length and straightness, are consonant with some such relatively superficial form of "mass-movement", nor can we forget the wide prevalence of similar movements in the area. Yet it is equally certain that there is some primary structure concerned in the "Blackdown line". The slipping is the result, not the cause of the Blackdown angle. If erosion were completely to remove the slipped mass, it would still be true that the outcrop of the edge of the Hythe Beds would turn through a right-angle at Blackdown, in such fashion as to suggest a local change of strike, and that the Weald Clay below conforms to a similar pattern. It seems probable that the primary structure involved is, in effect, a slight monocline throwing eastwards, as in the similar example of Hindhead. It is conceivable, though impossible to demonstrate, that there may have been some slight primary faulting on the same line, but it must be remarked that dip-faulting on so considerable a scale is rare in the Weald. Herein lies an important difference between the Blackdown structure and those of the Nutfield-Godstone district which, if they involve faulting at all, present instances of strike-faulting.

It is beyond question that a slight monoclinal structure of the type indicated would predispose towards secondary slipping such as has evidently occurred. To this extent, we conclude that the Blackdown slip is structurally guided and to this we attribute its general straightness of form.

THE DATE OF THE " MASS-MOVEMENTS "

It is, of course, impossible from the evidence recorded in this paper to assign any precise date to the several superficial structures described, and at first sight there might seem no reason to suppose that they marked any one particular period. Nevertheless, there are some suggestive indications of dating which deserve mention and further investigation.

In the first place it is evident that the scale of the movements is much greater than that of the landslips recorded during historical times, as, for instance, at Westerham in 1596, Toys Hill in 1756 [**11**] and at various times along the Leith Hill range. It seems very probable that it is to periglacial " freeze and thaw " conditions that we can attribute these larger movements. Moreover, in all cases the displaced masses have been subject to considerable reduction and dissection by erosion since they were emplaced. There has been time for valleys to pick out the major displacement planes and in some, as we have seen, the displaced mass has been almost isolated. Taken as a whole the evidence suggests a date anterior to the last glaciation. Supporting evidence of a relatively great antiquity comes from the distribution of chert and sandstone rubble-drift over the Weald Clay country. The latter shows a well-marked erosion level at about 200 feet which there is every reason to regard as the equivalent of the 200-foot platform north of the Thames—the Ambersham stage of J. F. N. Green. This surface is, however, generally free from rubble-drift. Rising above it are isolated hills and ridges which attain elevations of 300–320 feet ; these seem to represent an earlier surface of low relief which was dissected and largely destroyed in the formation of the later and lower platform. It is on these hill-tops that coarse chert and sandstone drift is conspicuous. A striking instance is the " county boundary ridge " mentioned above (p. 174) which, both east and west of the main road crossing at Cripplecrutch Hill, is thickly capped by such material, at a present distance of as much as three miles from the main Hythe Beds escarpment.[1] It seems very probable that the rubble-drift represents the distribution over the former plain, by solifluction or temporary torrential flows from snow-melt, of the broken rock-material from the scarp-slips. Below the toe of the Blackdown slip, along the road from Dial Green to Gospel Green and especially near Parkhurst, such material is much in evidence. Here and elsewhere it can be traced downwards on to hill-tops at 300–325 feet, but not lower. Vast quantities of the same material are found partly filling the miniature stream gorges of later date, as for example between Dial Green and Windfall-wood Common. It is inconceivable that it has been carried recently from the present escarpments, but points rather to the demolition and resorting of a widespread mantle accumulated in earlier times. Since the 200-foot platform is evidently anterior to the main or Chalky Boulder Clay glaciation north of the Thames, the 300-foot feature and its rubble-drift are phenomena of markedly earlier date, and the drift itself may well mark the first onset of periglacial or nivation conditions in the Weald. It would be too much to claim at present that the episodes of mass-movement on the escarpments are safely and indubitably linked with the rubble-drift of the plain, but there is at least a strong suggestion that this is so, and the relative age so indicated is wholly consistent with the state of erosion of the displaced masses.

CONCLUSIONS

The paper examines the structure of an important area in the Western Weald by reference to the attitude of the base of the Hythe Beds and of a datum horizon in the Weald Clay revealed by 6-inch mapping. The subdivision of the Weald Clay adopted agrees with that demonstrated by F. W. Reeves in the Henfield district and depends upon the recognition and tracing of the top of the main mass of bright red clays below the overlying sands or sandstones well seen near Fernhurst. The horizon in question appears to lie about 400 feet below the base of the Hythe Beds.

The data so obtained demonstrate the double culmination of the Fernhurst fold, indicate the approximate position of the eastern “ closures ” of the Fernhurst and Hindhead folds and the setting in of two further folds *en échelon*, with their axes passing roughly through Balls Cross and Dyer’s Cross. Light is also thrown on the rectangular bend in the Lower Greensand outcrop at Blackdown where there is evidence of a primary north–south structure, probably a gentle monocline throwing eastwards.

Rotational slipping and cambering is described at a number of localities along the Hythe Beds escarpment. The displacement on the eastern side of Blackdown is interpreted as essentially due to such mass movement co-operating with and guided by the primary structure on or near the same line.

---

[1] This rubble drift invites comparison with that described by H.M. Geological Survey near Newdigate [12].

The high state of dissection of the displaced masses and their probable association with a widely spread sheet of rubble-drift capping isolated hill-tops at about 300 feet in the Weald Clay lowland is taken to indicate a considerable antiquity for the mass-movements and they are tentatively ascribed to the first onset of periglacial conditions in the Weald.

REFERENCES

1. KIRKALDY, J. F. 1932. The Geology of the country around Hascombe, Surrey. *Proc. Geol. Assoc.*, 43, p. 127; and H. A. HAYWARD. The Geology of the Lower Greensand of the Leith Hill district. *ibid.*, p. 1.
2. The Report of the Weald Research Committee. 1928. *Proc. Geol. Assoc.*, 39, p. 226.
3. KIRKALDY, J. F. and S. W. WOOLDRIDGE. 1938. Notes on the Geology of the country around Haslemere and Midhurst. *Proc. Geol. Assoc.*, 49, p. 136.
4. REEVES, J. W. 1948. Surface Problems in the Search for Oil in Sussex. *Proc. Geol. Assoc.*, pp. 59, 240.
5. TOPLEY, W. 1875. The Geology of the Weald. *Mem. Geol. Surv.*, p. 109.
6. *ibid.*, p. 232.
7. *ibid.*, p. 114.
8. See 3 above, pp. 137–40.
9. GOSSLING, F. 1935. The Structure of Bower Hill, Nutfield. *Proc. Geol. Assoc.*, 46, p. 360.
10. GOSSLING, F. and A. J. BULL. 1948. The Structure of Tilburstow Hill, Surrey. *Proc. Geol. Assoc.*, 59, p. 140. *See also* **12**, pp. 11–16.
11. See 5 above, p. 316.
12. DINES, H. G. and F. H. EDMUNDS. 1933. The Country around Dorking and Reigate. *Mem. Geol. Surv.*, p. 157.

DISCUSSION

The PRESIDENT congratulated the author on establishing horizons in the Weald Clay which enabled the structure of that formation to be worked out in detail in the western Weald. The presence of small periclines *en échelon* in the Hythe Beds, each with an east–west axis, was of interest because these features continued at intervals at least as far east as the Medway.

The evidence for land-slipping seemed convincing and was comparable with other examples quoted. Similar coastal occurrences were accepted without question, and if these inland masses of Hythe Beds, obviously displaced from the escarpment, were attributed to strike faults, it was necessary to prove the existence of such faults.

With regard to the age of the slips, an age delimitation within the Pleistocene had been suggested for the Mereworth-Wateringbury mass and the relative age of a particular slip was indicated by its distance from the present escarpment and the amount of subsequent denudation.

DR. J. F. KIRKALDY congratulated the author on his instructive paper.

MR. H. R. LOVELY wished to be associated with Dr. Kirkaldy in congratulating Professor Wooldridge on his most interesting and instructive paper. He then recalled that during 1935 and 1936 he encountered a similar problem to that of Professor Wooldridge in separating the Weald Clay stratigraphically, as he was engaged in mapping the central region of the Wealden uplift for one of the major oil companies, which was interested in this territory as being potentially oil bearing.

He first obtained a clue to the subdivision of the Weald Clay from the Geological Survey Memoir on Lewes in which an early worker (? Martin) had zoned the local section of Weald Clay by means of sandstones and red clay bands. Investigation in the field showed that these red clay bands in particular were of value and could be easily recognised in poor ditch sections, road verges, and the most meagre of exposures by reason of the marked contrast in colour between them and the normal Weald Clay.

In 1935 a unique opportunity to study the distribution of the red clay bands was afforded by the spoil from a ditch cut in the grass verge across Ditchling Common which traversed the Wealden section virtually at right angle across the strike. This spoil was *in situ* and the various red clay bands, and to a lesser extent the sandstone members, could be clearly mapped. By careful pacing, and assuming a regional dip for the southern flank of the Wealden uplift (5°), it was possible to compile a reasonably good section of the Weald Clay with its various subdivisions and, speaking entirely from memory, there were three main and separate red clay zones represented, a thick zone corresponding to that used by Professor Wooldridge, and two thinner lying below it.

The speaker was satisfied that the red clay zones indicated relative position within the Weald Clay and used them throughout his automobile reconnaissance of the Central Wealden region in which every lane and minor road was traversed at from 10 to 15 miles per hour. At this speed the red clay could always be picked up and a short stop was generally sufficient to delimit the upper or lower boundaries of the particular zone on colour alone. As it turned out, no structures of any interest were disclosed in this region from the point of view of oil geology, but if there had been any it is considered that any red clay bed, particularly the thick one, would have been a suitable " marker " for detailed structural delineation.

It is of interest that this contributor also delineated the small red clay inlier near Kirdford, indicating hitherto unknown local doming of the Fernhurst anticline, that had been shown by Professor Wooldridge on his map. This identical mapping by two entirely unassociated geologists, separated by a number of years, lends confirmation of the value of the red clay.

Lastly, the speaker pointed out that it must be remembered that there is a regional thickening of the Weald Clay westwards from 600 feet, or less, in the Pevensey area of East Sussex, to over 1200 feet in that area of West Sussex described by Professor Wooldridge, and the red clay passing westwards did not necessarily maintain a constant position with reference to the top of the Clay, but changed in some proportion to the degree of thickening. Future investigators were advised, therefore, to consider the distribution of the red clay beds over the whole Weald by means of isopach maps, and convergence diagrams, before using them in any particular area for accurate mapping, and later transference of structure to a higher or lower horizon.

Professor S. E. HOLLINGSWORTH said that during an all-too-brief visit to the author's area, he had the pleasure of having some of the more spectacular features of the district demonstrated to him, and for that occasion, as well as for the paper read, he would like to express his sincere thanks.

Significant though Prof. Wooldridge's elucidation of the structure was, to many the high-light of the paper was the critical discussion of the dislocated masses of Hythe Beds along the edge of the Lower Greensand escarpment.

He was in full sympathy with the Professor's general conclusion that they were the result of shallow movements, due to a combination of topographical and structural control, that originated under specially favourable conditions a long way back in the Pleistocene. Prof. Wooldridge's demonstration of their dissected character, and of their association with remnants of rubble drift, was particularly significant.

He pointed to two aspects of the author's results which were of more than regional importance. First that the rubble drift was found on what appeared to be remnants of the surface at around 320 feet O.D., and to be absent from the 200-foot O.D. surface. This was a pointer to the necessity of further studies of the altitude distribution of drifts over a much wider area.

Secondly, as Prof. Wooldridge had said, the peculiar features of the detached masses of Lower Greensand invited comparison with the controversial features of the escarpment farther east, notably those at Bower Hill, investigated with such painstaking thoroughness by the late Mr. Gossling, and Tilburstow Hill recently described to the Association by Dr. Bull. Clearly, said Prof. Hollingsworth, a common origin seemed highly probable.

The President had referred to this group of phenomena as evident examples of landslips. Prof. Hollingsworth agreed in large measure that that was probably the solution if all the evidence now available was taken ; but as one who was not wholly satisfied that Gossling's evidence was conclusive he would like to say more about the significance of these occurrences. Moreover the history of their investigation marked an important phase in the development of our knowledge of the Weald that might not be without interest and value to younger members.

The Bower Hill–Tilburstow Hill series of tilted masses of Hythe Beds in front of the main Lower Greensand escarpment had an alignment suggestive of detachment along a line of tectonic significance. The topographical forms characteristic of landslips were conspicuously absent, and length of the individual masses parallel to the scarp was unusual for inland examples of that structure. No doubt such reasons led to the adoption of an interpretation by faulting on the Survey maps.

Discussion with members of the Weald Research Committee and with Survey Officers familiar with the Weald made it evident that large-scale superficial structures such as had been described from Northamptonshire occur there. Prof. Hollingsworth suggested that the Lower Greensand occurrences had a good deal in common with such structures, and were related both to them, and to the landslip as normally understood.

Initiation of gull-like tension fractures on a scarp face due to yielding of a weak underlying clay formation would favour free access of water to the base of even a moderately permeable stratum (e.g., with clay partings). On an undissected linear scarp face long fissures developing parallel to the face might well result in the breaking away of elongated strips.

Gossling had mentioned (1935, p. 386) a water-logged and snow-covered scarp during a glacial phase of the Pleistocene as presenting favourable conditions for slipping, and Dr. Bull suggested thaw and freezing conditions as a possible contributing factor in the displacement of the Tilburstow mass. Prof. Wooldridge had now brought forward strong supporting evidence.

From a further consideration of the phemonena in Northamptonshire and elsewhere it seemed probable that the fundamental factor in the remarkably low strength exhibited by the clays was itself a consequence of abnormal conditions not operative in this country in regions of comparable topography and structure. It was suggested that the major movements followed on the thaw-out, of a deep " permanently " frozen ground, say of the order of 100–200 feet. The latter, with a fluctuating lower limit, would be associated with a build-up of deep ice wedges, ice lenses and kindred phenomena such as were found in Alaska, Siberia, etc. The thawing-out left a loose textured soft clay, overlaid by loosely joined massive strata, the whole assemblage being one particularly liable to slipping, indeed the slipping might well take place in partially thawed areas as the downward limit of freezing rose. This suggestion could be regarded as an amplification or extension of the widely recognised moderately deep thaw-freeze processes which was general throughout southern England, but the consequences, particularly of its extension into the clays, were quite distinct.

Prof. Hollingsworth was inclined to think that such a hypothesis would fit the new evidence brought forward by the author.

Mr. W. H. Ward said that he had taken a particular interest in landslips and he was encouraged to know that Professor Wooldridge had found them a satisfactory explanation for features that had previously been mapped as tectonic faults. He had encountered several areas where landslips had been delineated by fault lines, for example, in the combes near Bath and south of Glenarm on the Antrim coast.

There seemed to be a need for a clearer distinction between a slip-plane of mass movement associated with relief and a tectonic fault. The former, given sufficient relief, could involve the shearing of thousands of feet of ground. Could ruptures on this scale be called slips or faults ?

He thought that Prof. Wooldridge should not be discouraged if the derelict form of the landslip did not fit Prof. Hollingworth's "classical" curved form. Landslips varied appreciably in the way they ruptured depending on the topography, the relative strength of the strata and their sequence ; yet they all followed the simple laws of mechanics. Many rotational slips in movement today, e.g., Folkestone Warren, did superficially possess a linear form. Several movements alongside each other moving to some extent independently at intervals could eventually coalesce into what appeared to be one large movement of linear form. A few thousand years of stagnation would readily conceal minor dislocations and enhance the general form of dislocation.

Prof. Wooldridge suggested the early Pleistocene for the occurrence of the Wealden landslips, but had also indicated a late Pleistocene valley deepening from the 300-foot level to about 200 feet. Surely it was quite likely therefore that movements had taken place from time to time right through the Pleistocene, since landslips invariably started by erosion at the toe where the ground was not submerged in ice or water.

Prof. Wooldridge's work was very valuable and the speaker hoped that the discussion would encourage him to find more landslips.

The Author replied briefly, and thanked the Association for the reception given his paper, and expressed his cordial thanks to Mr. F. Goldring for assistance in the field and for the photographs illustrating the paper.

FIELD MEETING IN THE LOWESTOFT DISTRICT

Friday, 1st July—Sunday, 3rd July, 1949

Report by the Director : D. F. W. Baden-Powell, M.A., B.Sc., F.G.S.

[*Received 12th September*, 1949]

Friday, 1st July. The party of 14 assembled at their headquarters at the Royal Hotel, Lowestoft, on Friday evening, and after dinner a short walk to the mouth of Lowestoft Harbour took the place of a more formal talk by the Director. The magnificent weather which greeted the party on its arrival continued throughout the meeting. Transport during the next two days was mainly by coach, with a minimum of walking ; this was made necessary by the great distances between the sections visited. Copies of a specially prepared diagrammatic section along the Waveney Valley were distributed, and this section is reproduced in Fig. 1.

Saturday, 2nd July. The first pit visited after leaving Lowestoft at 9.30 a.m. was Mr. Davey's sandpit one mile east of Bungay. Here the Director explained that most field meetings of the Association in East Anglia had been centred either farther south at Ipswich, or farther north at Norwich or Cromer, and that Lowestoft had been chosen as headquarters on this occasion, chiefly because the stratigraphy is more easily seen along the Waveney Valley than in the areas of greater glacial disturbance farther north and farther south. A brief outline was given of the deposits which occur in this district, and the sequence may be summarised as follows :

Peat }
Estuarine and marine deposits } The Broads

Erosion of Lopham Ford Gap.
Glacial outwash gravels (Gipping Glaciation).
Erosion
Hoxne Interglacial Series { Late Clactonian
{ Acheulian
Erosion
Lowestoft Boulder Clay
Erosion
Corton Beds (marine). Early Clactonian
Cromer Till
Pebbly Series
Cromer Forest Bed (or Chillesford Clay)

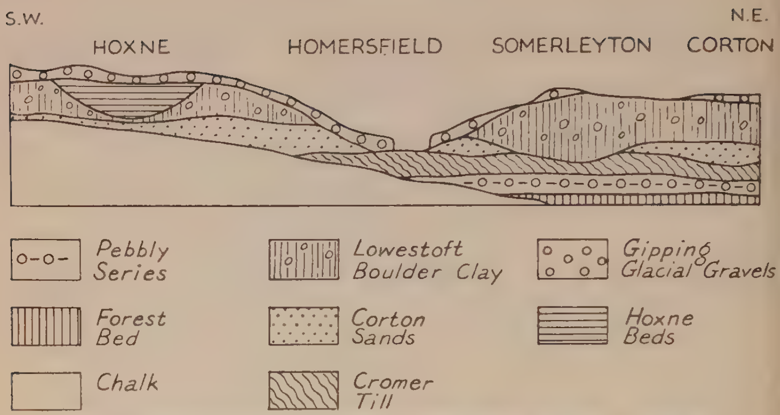


Fig. 1. Diagrammatic Section Along the Waveney Valley. Top of section at Hoxne about 100 feet above sea level. Length of section about 30 miles.

Davey's pit showed a great thickness of sandy Corton Beds, with banks of pebbles in the lower part, and although the party found no shells here on this occasion, it was pointed out that marine shells had been reported from a similar sand by the Geological Survey. Quite recently a horn-core of *Bos* cf. *primigenius* and an unidentified vertebra have been found in the uppermost gravelly layer in this pit, and Miss D. M. A. Bate has kindly examined the specimens. During the present visit a fragment of tusk was found *in situ* in the gravel. These are believed to be the first known vertebrate remains from the Corton Beds. Erratics of dolerite, basalt and Neocomian Sandstone were seen on the floor of the pit, and a large erratic of fresh basalt was found *in situ* in the gravel. A few flint flakes from this horizon (but from other pits) were shown to the party by the Director, who claimed that they might be humanly worked ; some of the party doubted the human origin of the flaking.

The party then went to Somerleyton Brickworks. Unfortunately the deposits here have not been worked for a number of years, but part of the Pebbly Series is still exposed in that part of the pit nearest to the railway station, and the junction of the overlying Cromer Till and Lowestoft Boulder Clay had been cleared for the party's visit by a small excavation on the east side of the old workings. An erratic of quartzose schist was found at the base of the Lowestoft Boulder Clay. Other erratics seen on the floor of the pit included dolerite, basalt and an interesting example of Serpulite Rock of Lower Kimmeridgian age, in which Dr. W. J. Arkell identified provisionally *Amoeboceras* cf. *kitchini* (Salfeld), *Pleuromya alduini* Brongniart and an *Astarte*. Lincolnshire is a probable source for this rock.

The next places visited were Fritton Decoy and Filby Broad, and the Director explained the difficulties in understanding the origin of the Broads, but said that recent bore holes had proved the existence of marine mud between two layers of peat, confirming that the Broads are cut-off remnants of estuaries, and pollen analysis has suggested that the marine layer belongs to the Sub-Atlantic stage of the Holocene period. A comparison was made between the formation of the Broads and that of the much earlier Cromer Forest Bed Series.

The party then went to the coast section at Scratby, where patches made up largely of shell fragments were examined in the Corton Beds. *Cardium* sp., *Cyprina* cf. *islandica* L. and *Turritella* cf. *communis* Risso were recognised, and a gasteropod, doubtfully *in situ*, which the Director has identified as a young *Neptunea antiqua* (L), but with coarse ribbing suggesting the extinct variety *subtornata* Harmer, only recorded previously from the Butley and Norwich Crags. A short discussion of the marine mollusca of the Corton Beds will be found in the Appendix of this report.

After tea at the Hut Hotel at Corton, the party walked from the southern end of the cliff exposure here to Corton Gap. By unusual good fortune, the sea had recently exposed part of the Forest Bed (or " Rootlet Bed " of the Geological Survey) at the base of the cliff. The Director explained that this seldom-seen peaty clay was originally classified as Chillesford Clay, but that he preferred to follow Clement Reid in considering it as a southerly extension of the Cromer Forest Bed. Unfortunately no fossils were found during this visit. The succession above this bed was well exposed in the cliff face, with Corton Beds between the Cromer Till at the base and the Lowestoft Boulder Clay at the top. The historic importance of the section was pointed out, because its examination by Trimmer more than 100 years ago led to one of the earliest attempts to sub-divide the glacial series. Some ruined cottages in process of falling down the cliff were a painful reminder of the rapid rate of erosion at Corton, and a summary was given of the views of Professor Steers that the southerly drift of beach material is held up at the mouth of Yarmouth Harbour, and that this accelerates the rate of erosion at Corton.

After dinner a few members of the party walked to the cliff section at Pakefield, where sand and gravel were seen to occupy most of the low cliff ; an erratic of bluish sandstone (rather schistose) and a worked flint flake of Corton type were found in the gravel, and their occurrence suggests the presence of Corton Beds here.

Sunday, 3rd July. Leaving Lowestoft at 9.30 a.m., the party went up the Waveney Valley to Beccles, where a short examination was made of the steep side of the valley which bounds the west side of the town. The date of the erosion of this slope is at least later than the Lowestoft Boulder Clay which caps the Corton Beds along the valley sides.

The next stop was at Hoxne, where a large disused pit south of Elm House Farm and east of the village was visited. The base of the Lowestoft Boulder Clay was seen here capping apparent Corton Beds, but no marine shells were found in the gravel under the boulder clay during this visit. The Geological Survey has recorded shell fragments from this gravel within two miles of Hoxne village, and *Purpura lapillus* L. has been recorded from a well-section in Hoxne itself. These facts suggest that the deposit underlying the bottom boulder clay in the Hoxne Series belongs to the Corton Beds, a point of great importance in the local stratigraphy. The Director, in answer to a question, stated that the abundance of chalk pebbles in the gravel might be expected here, near the shore line of the Corton Sea. An oolite pebble and *Gryphaea arcuata* Lamarck were found in the gravel, and a large erratic of Neocomian sandstone, probably from Lincolnshire, and apparently from the Lowestoft Boulder Clay, was found in the grass above the section.

The Hoxne brickyard was also visited, and the party was reminded that apart from its later fame, this site yielded the flint implements described by John Frere as long ago as 1797. No implements were found during the present visit, but the Director showed the party a twisted hand-axe which was discovered in 1948 near the top of the blue brickearth at the north end of the pit. New sections at the southern end showed several feet of reddish brickearth which is younger than the sequence known to earlier generations of geologists, and the following beds were exposed in the western face of the pit.

	Feet	Inches
Dark soil and sand	1	0
Unbedded glacial gravel	6	0
Blue clay	7	10
Black clay with freshwater shells	2	6
Grey clay	1	0
Dark Lowestoft Boulder Clay, to	0	10

Erratics found on the floor of the pit included basalt and a lump of felspar about four inches in diameter.

The party then drove to the joint sources of the Waveney and Little Ouse rivers at Lopham Ford Gap, and the Director pointed out that this is the lowest point in the main watershed of East Anglia, and that the difficulty of accounting for this Gap is partly met by two theories : either the capture of the upper Little Ouse by the Waveney, or as an overflow channel from glacier lakes in the Fenland contemporary with the obstruction of the Wash by ice during the Hunstanton Glaciation.

During the return journey to Lowestoft, pressure of time necessitated a curtailment of the visit to the pits at Roydon, west of Diss.

There was time for the party to see that Lowestoft Boulder Clay occurs here, and also boulder gravel with an amazing variety of erratics, including many unusual Jurassic rocks. In the pits one mile south-west of Harleston, a pile of enormous erratics was investigated near a washing plant on the south side of the road, and Dr. Arkell identified rocks with *Exogyra virgula* (Defr.) and *Aulacostephanus* sp. from the Pseudomutabilis Zone of the Kimmeridgian, and another with *Pictonia* sp. from the base of the Kimmeridgian. Unfortunately the exact provenance of these boulders is doubtful. A large pit on the north side of the main road here was visited next, which shows glacial gravel overlying what appears to be Corton Beds. An erratic, which has been found recently in the glacial gravel, was originally thought to be a rhomb porphyry, but it has now been sliced and found to contain porphyritic andesine; it resembles one of the acid lavas found in glacial gravel at Coe's pit, Ipswich.

Finally a tantalisingly short view was obtained of the extensive gravel pits at Homersfield, where the Director explained that mechanical diggers had obliterated the sections with almost complete success, but that the gravel is known to be unbedded and unsorted, in spite of the fact that the surface of the ground here is in the form of a flat-topped terrace. This suggests an outwash sheet from an ice-front rather than a river terrace like those outside the glaciated area. The opinion was expressed that much of the gravel seen on the day's journey from Hoxne onwards consists of outwash from the ice of the Gipping glaciation, when the ice-front lay to the west of most of the existing Waveney Valley. Vertebrate remains are known from these gravels at Homersfield, and Mr. H. E. P. Spencer told the party that during the years 1942 and 1943, when large quantities of gravel were excavated for aerodromes, numbers of mammalian bones were found here, of which a few went to the Ipswich Museum, where a comprehensive collection of Pleistocene mammalian remains is being accumulated. The bones from Homersfield included a large part of a skull of *Rhinoceros tichorhinus*, from which the palate and teeth are missing; a molar of *Elephas primigenius*, and a horn-core of *Bos primigenius*.

The party returned to Lowestoft for tea before catching trains back to London, and a vote of thanks was proposed by Mr. A. G. Bell on behalf of the Association to the Director and to Mr. W. E. Smith, B.Sc., secretary of the excursion.

Appendix

Note on the marine mollusca of the Corton Beds

By D. F. W. Baden-Powell, B.Sc., M.A., F.G.S.

During the Lowestoft Field Meeting, the Director stated that the marine fauna of the Corton Beds is of special interest, because it includes a mixture of extinct species with indicators of both warm and cold climates. He also said that there is good reason to believe that the fauna is not derived from the Crag, although it is possible that some of the commoner species might be derived from the Cromer Till. As the existing knowledge of the Corton fauna is scattered through a wide variety of publications, this seems a good opportunity to collect some of the facts, because the Corton Beds may be useful for future correlations of Pleistocene deposits.

The main information about this fauna is to be found in the Geological Survey Memoirs dealing with Cromer, Norwich and Lowestoft, and in the Monographs of the Palaeontographical Society by S. V. Wood on the "Crag Mollusca" and by F. W. Harmer on the "Pliocene Mollusca". Not all the shells from this horizon in various museums have been revised by the writer, but the identification of most of the significant species seems reliable.

The general distribution of the Corton Beds so far recognised in East Anglia is from Cromer to Pakefield and possibly as far south as Wickham Market, and from Lowestoft westward to the neighbourhood of Hoxne. The thickness varies from 0 to about 80 feet, and the height above sea level near Hoxne is about 100 feet (33 m.), so that a submergence of at least this amount is probable.

The warm indicators are :

Limopsis pygmaea Philippi.
? *Astarte incrassata* (Brocchi).
Woodia digitaria L.
Loripes divaricata L.
Cardita corbis Philippi.
Cytherea rudis Poli.
Corbula contracta Say.
Dentalium dentalis L.
Dentalium vulgare da Costa.
Calyptraea chinensis L.
Trophon muricatus Montagu.

The cold indicators are :

? *Nucula tenuis* Montagu.
Leda lanceolata Sowerby.
Leda oblongoides Wood.
Astarte borealis Chemnitz.
? *Cardium islandicum* L.
Venus fluctuosa Gould.
? *Tellina calcarea* Chemnitz.
Saxicava arctica L.
Margarites groenlandica Chemnitz.
Scalaria groenlandica Chemnitz.
Natica clausa Broderip and Sow.
Amauropsis islandica Gmelin.
Trophon clathratus L.
Buccinum coerulea Sars.
Bela exarata Möllre.

Forms which are extinct so far as is known :

Nucula cobboldiae Sowerby.
Astarte burtini. La Jonk
Astarte omalii La Jonk.
Woodia hoptonensis Wood.
Lasaea intermedia Wood.
Cardita scalaris Leathes.
Erycinella ovalis Conrad.
Chemnitzia internodula Wood.
Natica cf. *hemiclausa* Sow.
Cerithium tricinctum Brocchi.
Purpura incrassata Sowerby.
Columbella sulcata Sowerby.
Trophon billockbiensis Wood.
Trophon mediglacialis Wood.

Tellina obliqua Sowerby.
Spisula arcuata Sowerby.
Calliostoma noduliferens Wood.
Rissoa semicostata Woodward.
Turritella incrassata, var. *minor* Harmer.
Scalaria aldebiana Sacco.
Nassa granulata Sowerby.
Nassa elegantula Harmer.
Nassa pusillina Wood.
Nassa reticosa Sowerby.
Bela assimilis Wood.
Bela dowsoni Wood.
Paludina glacialis Wood.

There are also many species still found living in Britain. A very similar mixed assemblage is now known from interglacial marine deposits at a number of other British localities.

GRAVITATIONAL SLIDING

A lecture delivered to the Association on 2nd December, 1949

By the late Dr. A. J. BULL

SUMMARY.—The Author gives examples of large-scale landslides, which he suggests may often explain complicated tectonics, without the necessity for invoking the operation of deep-seated forces.

RECORDS of rocks sliding downhill are common. Examples of large-scale sliding are the landslides in the San Juan Mountains, Colorado, [**12***] one of which covers 10 square miles, and the rockfall of Flims, Switzerland [**11**], which has been estimated at 12 cubic kilometres. Slips on escarpments and other places, in which the dip increases as the moving mass goes down, are now often described as rotational slipping, and a similar movement naturally happens to the ice in corrie glaciers. The slips that are being considered in this lecture are chiefly those in which a mass of consolidated rock has moved on a weaker stratum, for example the Bindon landslip of 1839 [**1**], or where more than one slide plane has contributed to the movement.

The disturbed beach on the east side of Beachy Head, Sussex, has been visited by the Association. On this complex beach the Upper Greensand is repeated five times in roughly parallel outcrops. At one time the lecturer inclined to the view that the faulting might be the result of deep seated movements. In the discussion at that time the late G. W. Lamplough expressed the opinion that it was merely slipping from the cliff, and further work has shown this to be correct [**13**, p. 299].

One of the simpler cases in which the force producing the folded structures could not have been applied from outside is that of the Jura Mountains. These mountains consist of Jurassic beds which are folded in sharp anticlines and where the folds are not close the synclines between tend to be flat. These anticlines are in the form of long domes which pitch out and are followed by synclines along their axes. The whole is bowed to the north-west. Buxtorf showed from observations on two tunnels that the structures did not extend below the anhydrite beds of the Middle Muschelkalk, for the Buntersandstone below is unfolded, therefore no force from below is involved. As there is no concentration of the folding in any one district the structure could not have been produced by any horizontal force applied from outside, and gravity is the only force that could possibly be effective throughout the whole of the sheet of sediments. I see no escape from the conclusion that the great stratified sheet has slid on the weakest bed and folded under the force of its own weight ;

---

* For list of References see p. 201.

it follows that at one time the sheet was tilted towards the north-west. Small-scale representations of the structure have been seen in sliding snow and other materials [**6**].

Here one may refer to the large-scale folding of Asmari Limestone in Persia. This is on thick salt beds, and may well have been produced by the force of gravity taking advantage of a slight tilt.

A common feature is that of intraformational folding, where the folding is confined to one or more beds in a stratified series. An example of this kind was revealed in the railway cutting at Brockley, South London, when the bank was cleaned in 1922. The beds are part of the Woolwich Series and the base of the London Clay. Sands and clays with *Cyrena* are divided by a freshwater limestone with *Paludina*, etc., the whole showing two overfolds with a syncline between them. C. E. N. Bromehead [**4**] expressed the opinion that the folds were superficial rather than tectonic, and were due to the slipping of the London Clay from the high ground of Hatcham, the folds being produced by the moving mass of clay above. As the cutting is not along the dip, the folds must be much more acute than was revealed.

A similar fold occurs in the western part of the Sustenstrasse, Switzerland, where a deeply cut valley reveals the structure. The valley shows the granite of the Aar Massif with Mesozoic and Tertiary beds on it. The light yellow Triassic Dolomite resting directly on the crystalline enables the structure to be followed. Under the Mahren this bed is repeated by reversed faulting, and lower down the valley above the village of Gadmen there is a fold of the same shape as those at Brockley.[1] All these rocks are autochthonous, but the Helvetic Nappes to the north-west have passed over them, and these can only have been moved by the force of gravity. It is therefore suggested that the folds in these well consolidated rocks are due to the same cause as the Brockley folding.

The literature contains records of a great number of disturbances of this kind. For instance in his studies of Gravitational Tectonics at Shorncliffe, S.E. Queensland [**10**], R. W. Fairbridge illustrates some which are undoubtedly due to the movement under gravity of upper beds over lower ones. Other examples are the folding within the Tunbridge Wells Sand at Uckfield, Sussex, and those described by J. Challinor from Aberystwyth, Wales, [**7**].

It has been suggested above that some tectonics of the autochthone have been produced by a nappe moving over it under the force of gravity, and it is therefore interesting to consider Collet's mapping of the south face of the Hockenhorn [**8**, p. 265] (in the Bernese Oberland) which shows the Nappe de Morcles inverted on the autochthone. The section is east–west and the movement of the nappe has been to the north. The summit of the mountain consists of a Palaeozoic paragneiss now resting on the Triassic Dolomite which was originally deposited on it, while below are the higher Mesozoic strata much disturbed. The autochthone upon which this nappe has come to rest is less disturbed, and consists essentially of Triassic Quartzite on Gastern Granite. A neighbouring valley shows a most interesting contact [**8**, p. 272], in this case the Dolomite on the Gastern Granite has given way and mixed with superficially decomposed granite to form a shatter zone some 10 feet thick between the apparently undisturbed granite below and Jurassic Dogger and Malm above.

---

[1] Dr. Bull had intended to revisit Switzerland in June 1950 to take photographs of the folding described in this paragraph. After his death Professor Rutsch and Professor Cadisch tried unsuccessfully to obtain what was wanted, and the Geologists' Association wishes to record its thanks.

Thus the rocks that are sufficiently consolidated shatter rather than fold, and in the extreme case of a gneiss being broken the junction of the moving parts will be a mylonite, as Prof. Collet showed the Geologists' Association party in 1926.

When thick beds break under the force of gravity at many horizons, then most complicated tectonics may be produced. Particular reference is here made to the work of R. A. Baldry and C. Barrington Brown [**2**], [**3**], [**5**]. It is from their work that the title of this lecture is taken. The oil bearing strata of Peru and Bolivia (Middle Eocene to Lower Miocene) are traversed by slip-planes dipping at 7° to 10° which have produced horizontal movements up to 15 miles. In soft strata these slip-planes maintain low angles, but they break across hard bands. These flatter portions simulate unconformities, while the steeper parts have the appearance of normal faults. They bifurcate and rejoin enclosing rafts. In suitable material the movements have produced breccias, which in Peru reach a thickness of 600 feet. In softer materials that will flow readily the fine intricate patterns have been called sealing-wax folding. There are also sandstone dykes which originate from the slip planes. These complex beds occur between the Amotape Mountains and the sea, towards which the sliding has been directed. These movements have probably continued intermittently since the initial deposition of the Tertiary sediments.

In the examples given above the tectonics can be attributed to the action of gravity upon rocks that have in some way been disturbed and become unstable, for gravity tends always to stabilise conditions in the crust. It is indeed remarkable that the departures from complete isostatic adjustment are so small ; Dr. R. B. Cooper has recently commented on this and pointed out that gravity anomalies are generally only about ± 20 mgals. [**9**]. The tendency to stability can be disturbed by radioactive heat causing thermal expansion, and also by the changes in density which that heat can induce by altering the crystallographic structures of deep seated rocks. In the study of tectonics no other forces have been found which are capable of producing the diversity of structures in the earth's crust.

REFERENCES

1. Arber, M. A. 1940. The Coastal Landslips of S.E. Devon. *Proc. Geol. Assoc.*, 51, pp. 257–71.
2. Baldry, R. A. 1932. The Clay Pebble-bed of Ancon, Equador. *Geol. Mag.*, 69, pp. 145–6.
3. ———. 1938. Slip-planes and Breccia zones in the Tertiary rocks of Peru. *Quart. Journ. Geol. Soc.*, 94, p. 347.
4. Bromehead, C. E. N. 1922. Excursion to Brockley. *Proc. Geol. Assoc.*, 33, p. 77.
5. Brown, C. Barrington. 1938. On a theory of Gravitational Sliding applied to the Teritary of Ancon, Equador. *Quart. Journ. Geol. Soc.*, 94, p. 360.
6. Bull, A. J. 1943. The Compression of a Sheet. *Proc. Geol. Assoc.*, 54, pp. 185–9.

6a. ———. 1949. Note on a Possible Origin of the Alps. *Proc. Geol. Assoc.*, 60, pp. 161–4.

7. Challinor, J. 1949. The Origin of certain rock structures near Aberystwyth. *Proc. Geol. Assoc.*, 60, pp. 48–53.
8. Collet, L. W. 1947. La Géologie du versant Sud du massif de Gastern. *Eclogae Geologicae Helvetiae*, 40, pp. 257–81.
9. Cooper, R. B. 1950. Contribution to a discussion. Abstracts *Proc. Geol. Soc., Lond.*, 1461, p. 80.
10. Fairbridge, R. W. 1948. Gravitational Tectonics at Shorncliffe, S.E. Queensland. *Proc. Roy. Soc. of Queensland*, 59, pp. 179–201.
11. Heim, A. 1933–4. The Rockfall of Flims. (Translated by E. Montag). *Proc. Liverpool Geol. Soc.*, 16, pp, 139–41.
12. Howe, E. 1909. Landslides in the San Juan Mountains, Colorado. U.S. Geol. Sur., *Professional Paper 67*.
13. Milner, H. B. and A. J. Bull, 1925. Geology of the Eastbourne–Hastings Coastline. *Proc. Geol. Assoc.*, 36, pp. 291–320.

WHITSUN FIELD MEETING

3rd to 6th June, 1949

THE WOOLHOPE DISTRICT AND MAY HILL

Report by the Director : R. W. Pocock, D.Sc., F.G.S.

[*Received 4th November*, 1949.]

THE object of this meeting was to examine the geology and physiography of the Woolhope district in some detail and to compare it with the May Hill district to the south.

Thirty-two members of the Association assembled at the Kerry Arms Hotel, Hereford, on the evening of Friday, 3rd June, and the Director gave a short talk on the area to be visited. The Secretary, Miss M. O. Morris, distributed an illustrated pamphlet descriptive of the general succession of the Silurian rocks and the special features of interest.

The following morning, 4th June, the party with the addition of four members of the Woolhope Club, left headquarters at 9 a.m. and travelled by coach to Priors Frome where the junction of the Downtonian beds and Upper Ludlow was examined and a bone bed, apparently the equivalent of the Ludlow Bone Bed, was seen. The party went up the hill to Sufton Cockshoot to visit a quarry in Aymestry Limestone showing nodular structure and strong joints and from this point ascended Backbury Hill, passing over Lower Ludlow shales from which a few specimens of *Monograptus sp*. were obtained. From the top of the hill at Adam's Rocks, a broken mass of Aymestry Limestone, the Director pointed out the remarkable features of the Woolhope Dome ; the central core of Llandovery Sandstone with overlying Woolhope Limestone and the parallel ridges of the Wenlock and Aymestry limestones which, though broken by many faults and in places cut out by strike faults, encircle the central area and are particularly well seen from this viewpoint. Continuing downhill through the woods the party rejoined the coach at Clouds on the road to Checkley.

After passing through Checkley and by Bannut Tree, a halt was made at Canwood Corner and a short walk led to a line of old quarries in Wenlock Limestone, in the woods under Little Hill, where from the old spoil heaps a good variety of Wenlock Limestone corals and brachiopods was obtained. Returning to the road the drive was continued over the Wenlock Limestone ridge across the outcrop of the Lower Ludlow to the Aymestry Limestone of the outermost ridge at Woolhope Cockshoot. From this point a fine view is obtainable of the Malvern Range to the north-east. From the Cockshoot the road to Rushall was followed with a halt on the way to inspect "The Wonder" landslip of 1575, due to movement of Upper Ludlow beds on seams of unctuous clay. A good section of Upper Ludlow Beds was seen here. In a roadside section at Rushall the lowest beds of the Downtonian with the Bone Bed at their base are seen to rest on Upper Ludlow Beds. The Bone Bed contains good specimens of the small spherical fossil *Pachytheca* as well as the usual spines and teeth of fishes. From Rushall the party drove to the Wallwyn Arms, on the Ledbury–Ross road at Much Marcle where a halt was made.

From Much Marcle the drive was continued to Preston Cross and, turning to the left, to the crossroads at the Trumpet. Turning left again through Tarrington and Stoke Edith the party arrived at the small hamlet of Perton where they spent much time in the old Perton Quarry where the Chonetes Beds of the Upper Ludlow are covered by carbonaceous sandstones and grey-green shales with *Eurypterus* and *Pterygotus* in abundance. From these beds members of the party obtained at least six specimens of the problematical and extremely rare fossil *Actinophyllum* and many carbonised specimens of *Pachytheca.*

On returning to Tarrington tea was provided at the "Foley Arms" where Murchison stayed when he was studying the district for his account in *The Silurian System.* After tea the drive was continued to Shucknall Hill, to the north, where the members left the coach and walked up the hill into the large Aymestry Limestone quarry which shows deeply grooved and slickensided surfaces on a steep dip face of the limestone. The party continued to Bartestree and the old quarry in the Bartestree Dyke was entered with some difficulty as it is now much overgrown. The dyke is, however, still quite well exposed at the south-west end of the quarry with a width of about 35 feet and the altered Old Red Sandstones and marls on both sides were examined up to the line of contact. The dyke was described by Reynolds, in 1908, as a composite intrusion of several allied though differing types of dolerite and basalt. Rain prevented detailed tracing of the contacts and after a scramble out of the quarry the members returned to the road and drove back into Hereford.

On Sunday, 5th June, the party left headquarters by coach at 9.30 a.m. for Mordiford, entering the Silurian area of the Woolhope dome by the valley of the Pentaloe Brook on the line of the Rock Fault. At Scutterdine the old quarries in the Woolhope Limestone were examined and the party walked through the fields past Littlehope and up the dip slope of the Woolhope Limestone. At the top of the slope a section shows the highest beds of the Llandovery Sandstones which contain thin bands of shelly and crinoidal limestone. This was the locality where the rare crinoid *Petalocrinus* was first discovered in this country, as described by the Director in 1930. Some time was spent here and a number of arm fans of the crinoid were found, together with large corals and brachiopods including *Stricklandia lirata* which is common at this horizon. A few yards west of this section the Director pointed out the line of the Wyla thrust fault which repeats the outcrop of the Woolhope Limestone and of the Petalocrinus Limestone. A section at Haughwoods Cottage was next examined. This shows transition beds from the Llandovery Sandstone to the Woolhope Limestone.

Continuing up the steep road through Haugh Wood over the Llandovery Sandstones the road passes onto Broadmoor Common at Haughwoods Gate across an important thrust fault. At Welcheston Court the outcrop of the Petalocrinus Limestone crosses the field behind the house and here the members hunted successfully for specimens of the crinoid. Driving on to the village of Woolhope refreshment was obtained at the Crown Inn. After lunch the party continued on the Fownhope road to Rudge (Buildings) Farm, where they walked over the fields to an outcrop of the Petalocrinus Limestone which however was found to be obscured and only a few fragments were picked up, with some of the large corals associated with the limestone. Returning to the road the drive was continued to Fownhope and on to Brockhampton Court Hotel, where tea had been arranged. After tea the road to Capler Hill was taken and a halt made at a fine viewpoint overlooking the great bend of the Wye at Ballingham. Here also a quarry in Old Red Sandstone, from which came the stone for the new west front of Hereford Cathedral, was examined. The return journey to Hereford lay through Fownhope and between the Wye and the steep western margin of the Silurian area to Mordiford and thence direct into the City.

On Monday, 6th June, the members left headquarters at 9 a.m. and drove by the Ledbury road to Tarrington and the Trumpet. This route gave good views of the northern slopes of the Woolhope dome. From the Trumpet the route lay south through Little Marcle to Dymock over Old Red Sandstone. Between Dymock and Newent the road passes from Old Red onto Bunter Sandstone, resting on the thin Coal Measures of the Newent Coalfield. Passing south through Newent to the main Gloucester–Ross road near Huntley and turning west the old Huntley quarry on the north side of the road was reached in a short distance. In the quarry the Director drew attention to the position of the quarry up against the fault between the Trias and the older rocks and made a few remarks on Callaway's correlation of the rocks in the quarry with the Longmyndian of Shropshire and Old Radnor. He also suggested that a detailed survey of the immediate neighbourhood of this outcrop of old rock might yield results of interest. A search should be made for any indication of Cambrian rocks because these were present in the Southern Malvern area and had also been described from the Tortworth area, on the same north–south axis, by Stanley Smith and Stubblefield in 1933. The next halt was at the Inn at Dursley Cross from which point the party walked to the top of May Hill, the

Director pointing out the coarse conglomeratic Llandovery Sandstone, which underlies the finer flaggy beds and shales which alone are exposed in the Woolhope Anticline. Descending the steep western slope of the hill to May Hill Farm the Director described where he had found exposures of the Petalocrinus Limestone. Here the President proposed votes of thanks to those responsible for the arrangements. The party then walked to the old quarries in Wenlock Limestone to the south-west at Old Hobbs and Coleman's Wood and many typical fossils were obtained.

On returning to the coach the drive was continued towards Ross but, as there was still time in hand, a detour was made through Aston Ingham to Gorsley, to visit a working quarry in the Aymestry Limestone which is of special interest, as it appears to provide evidence of an unconformity between the Downtonian and the underlying Silurian rocks. In this quarry beds of yellowish carbonaceous sandstone comparable with the Downton Sandstone rest on the Aymestry Limestone with perhaps some small intervening thickness of Upper Ludlow Beds. To the south in the May Hill ground, it has been remarked that no Lower Ludlow or Aymestry Limestone occurs and that the Wenlock Limestone is succeeded by sandstones of Upper Ludlow age. It is here suggested that these sandstones may be of Downtonian age and not Upper Ludlow and that the whole of the Ludlow Series may be cut out by the unconformity in the May Hill district.

Leaving this interesting locality the drive was continued to Ross where a visit was paid to the public garden overlooking the big horseshoe bend of the Wye, and a grand view away to the Welsh hills. Returning to the coach, the return run was made to Hereford.

REFERENCES

1. CALLAWAY, C. 1900. On Longmyndian Inliers at Old Radnor and Huntley (Gloucestershire). *Quart. Journ. Geol. Soc.*, 56, pp. 511–20.
2. GARDINER, C. I. 1920. The Silurian Rocks of May Hill. *Proc. Cotteswold Nat. F.C.*, 3, pp. 185–218.
3. ———. 1927. The Silurian Rocks of Woolhope (Herefordshire). *Quart. Journ. Geol. Soc.*, 83, pp. 501–50.
4. ———. 1934. The Geology of the Gloucester District. *Proc. Geol. Assoc.*, 45, pp. 109–44.
5. POCOCK, R. W. 1930. The *Petalocrinus* Limestone Horizon at Woolhope, Herefordshire. *Quart. Journ. Geol. Soc.*, 86, pp. 50–62.
6. ——— and T. H. WHITEHEAD. 1948. *British Regional Geology, The Welsh Borderland.* Second edition.
7. STAMP, L. D. 1923. The Base of the Devonian. *Geol. Mag.*, 60, p. 276.
8. STRAW, H. S. 1926. Notes on the Genus *Actinophyllum. Mem. Manch. Lit. Phil. Soc.*, 70, pp. 133–9.
9. STRICKLAND, H. E. 1853. Ludlow Bone Bed. *Quart. Journ. Geol. Soc.*, 9, pp. 8–12.

Maps : 1in. Geological O.S. 43 NW. and NE. for Woolhope, 43 SE. for May Hill. 1in. Topographical Sheet 142 (new popular) for Hereford and Woolhope, Sheet 143 for May Hill.

THE RADIOLARIA OF THE HAWASINA SERIES OF OMAN

By A. G. DAVIS, F.G.S.

[*Received 1st July*, 1949]

SUMMARY.—Two new genera of Radiolaria, previously placed in the Recent genus *Sphaerozoum* Meyen, are described. One of these, *Mayenella*, is used as a Mesozoic index fossil. Six new species are also described.

RADIOLARITES are often important constituents of the folded zones arising out of the major geosynclines ; they occur in many parts of the world with a wide range of geological age. The study of any folded area, or tectonic unit, may be considerably enhanced if the radiolarites present can be assigned to a precise age but hitherto it has not been possible to distinguish index fossils among the radiolaria. (Tan, 1931, p. 95)*. Age determination is dependent upon the presence of macro-fossils in the accompanying strata but usually the position of the radiolarite is confused by tectonics and macro-fossils are rarely available.

In mapping south-western Iran the geologists of the Anglo-Iranian Oil Company found that certain structural problems could only be resolved if index fossils could be discovered in the fauna present in the radiolarites themselves and to this end research was initiated by Dr. G. M. Lees. The honour of taking up this study was entrusted to the writer, who was provided with materials from Iran and other parts of the world. The present account has been considerably influenced by these earlier studies, the results of which it is intended to present in a future communication.

The Hawasina Series of Oman (Lees, 1928, pp. 599–601) consists of a great thickness of red and green hard splintery shales and thin bedded red and green cherts with groups of limestones and hard calcareous sandstones. Everywhere the Series is strongly crumpled and confused and exact thickness measurements are not possible though the total may be of the order of 5000 feet. This group of beds occurs between a strong rigid limestone series and a mass of basic igneous rocks and serpentines, and, because of relative incompetence, the contacts are nowhere normal and large-scale thrust faulting has been suspected. The limestones apparently beneath the cherts at Wadi Adi near Bait al Falaj, where the present collection was made, pass down into fossiliferous Permian but the age of the upper part is unknown ; the group may be Jurassic or Lower Cretaceous. The zone as a whole was strongly folded at an uncertain time in the Cretaceous ; the movements were pre-Maestrichtian because Maestrichtian limestones and conglomerates are transgressive and contain detritus of the radiolarian cherts. By analogy with south-western Iran it is thought that the folding phase occurred during the Senonian; the age of the Hawasina Series must therefore be pre-Senonian.

---

* For list of References see p. 215.

In the Zagros mountains near Shiraz, Gray (1949, p. 58) has described extensive thrust sheets, 10,000 to 15,000 feet thick, partly made up of radiolarian cherts and overthrust on Cretaceous rocks, with a forward carry of some 30 miles. Subsequent erosion of the cover has revealed the thrust sheets over wide areas and in places has exposed the underlying autochthonous rocks in tectonic windows. Lees (*op. cit.*, p. 601) is of the opinion that the radiolarite zone, with its associated basic igneous rocks, is continuous from Oman through south-western Iran into Kurdistan and Turkey, and that the complex of southern Cyprus may be essentially part of the same zone. (See also Henson, 1949, p. 47.)

The material studied consisted of 23 thin sections of radiolarites prepared from specimens collected by Dr. E. Lehner and Mr. D. C. Ion from the Hawasina Series of Bait al Falaj, near Muscat, Oman.

All specimens were collected from the same chert series in which different shades of colour, mainly red, brown and green, were very common. The red specimens were found to be tightly packed with radiolaria forming a major constituent of the rock. The green samples appeared in thin section to be straw-coloured and their radiolarian content was much smaller.

The thin sections forming the basis of this study have been presented to the Trustees of the British Museum (Natural History) and they have been registered in their collections (Reg. Nos. PR. 50-74).

Radiolaria as palaeontological controls

In the past radiolaria have been considered of very slight value, if any, either for age determination or long range correlation. In the writer's recollection this was once also believed to be true of the foraminifera, and although it is not claimed that the radiolaria may become equally useful aids in stratigraphy, it is here suggested that with further research they may be rescued, as the foraminifera have been, to minister to the aid of the stratigrapher (see Glaessner, 1945, Chapter 1.) It is estimated that some 800 fossil forms of radiolaria are known, not a large number compared with other fossil groups, and it would not be a superhuman task to re-study them provided the types, mainly in German museums, have not been destroyed. A contributory factor to the neglect of this branch of palaeontology is the manner in which Rüst, the foremost worker on these fossils, interpreted and figured them. There can be no doubt that the descriptions, particularly the figures, are idealised, and one may be forgiven for concluding that Rüst tried to emulate his great contemporary Haeckel. Radiolarites and their faunas from many parts of the world still await description or remain little known, and it is very important that such a gap in our knowledge should be lessened. To this end the writer has studied a number of collections from Iran, Iraq, Turkey, Russia and North America. Palaeontological descriptions and faunal lists have been compiled as a result of this work and much information in manuscript has accumulated for use in comparing and correlating other faunas.

At the present stage an indicator, *Meyenella* gen. nov. (p. 211), is used on a rough statistical basis ; a count of 5 examples present in an average rock slice of 2 sq. cms. suggests strongly that the sample is of Jurassic age. A scrutiny of associated forms is usually necessary for confirmation but the behaviour of the indicator is of significance.

A count of 1 in 5 samples (=10 sq. cms. of rock surface examined) suggests high Jurassic or the Jurassic-Cretaceous boundary. Above this the indicator may only occur once or twice in 40 to 50 samples. The Triassic-Jurassic boundary is indicated by the presence of less than 3 in a single sample. In the Palaeozoic the proportion is even less. Although the radiolaria have been mistrusted as indices, it must be granted that if an approximate age can be assigned to a radiolarite by the presence of an indicator it is a promise of success for future work on these lines. At present the use of *Meyenella* as an indicator is applicable to the radiolarites of Europe, Asia and Australia, suites of samples for the remaining continents have so far not been available.

The preparation of radiolarites for examination is similar to the methods used in petrological practice. The examination of crushed chips immersed in water or oil was found helpful at times and, more rarely, etched surfaces were prepared for examination by the use of alkalis or acids.

The writer's thanks are here acknowledged to the Chairman and Directors of the Anglo-Iranian Oil Company for their permission to publish these results. To Dr. G. M. Lees he is much indebted for help and encouragement. He is also grateful to the Trustees and officials of the British Museum (Natural History) for facilities for research and to Mr. C. D. Ovey for access to the type material in his care.

SYSTEMATIC DESCRIPTIONS

CLASS : RADIOLARIA[1]
SUBCLASS : SPUMELLARIA
ORDER : SPHAERELLARIA
FAMILY : SPHAEROIDAE

GENUS : *CENOSPHAERA* EHRENBERG 1854

CENOSPHAERA spp. indet. (PR. 51).

Several species are no doubt present but their state of preservation does not allow of specific distinctions being made. They are so abundant as to form a very considerable constituent of the radiolarite.

---

[1] The classification of Gamble is adopted in this paper (see Ray Lankester 1909, pp. 144–51).

Distribution. Upper Jurassic, Hawasina Chert Series, near Muscat, Oman.

GENUS : *ELLIPSIDIUM* HAECKEL 1887

ELLIPSIDIUM sp. (PR. 50)

A single example only. The lattice of the capsule is not preserved but the spiny exterior suggests that this form is close to *Ellipsidium macrostylum* Rüst 1898 and *Ellipsidium microporum* Rüst 1898, both from the Jurassic of Cittiglio, Italy.

Distribution. Hawasina Chert Series, Muscat, Oman.

GENUS : *XIPHOSPHAERA* HAECKEL 1881

XIPHOSPHAERA sp.

Plate 7, Fig. 1 (PR. 50)

The structure of the central capsule is obliterated but the form is very close to *Xiphosphaera globosa* Rüst 1885 from the Neocomian of Urschlau.

Distribution. Hawasina Chert Series, Oman.

GENUS : *CENELLIPSIS* HAECKEL 1887

CENELLIPSIS sp. cf. *MONOCEROS* RÜST 1885

Plate 7, Fig. 2. (PR. 51).

The Oman form differs from Rüst's species in having a more globular capsule. Only two localities are known for the species, the Jurassic jaspers of West Switzerland (Rüst 1885) and the Hawasina Chert Series of Oman.

GENUS : *STAURODORAS* HAECKEL 1881

STAURODORAS MOJSISOVISCI DUNIKOWSKI 1882

Plate 7, Fig. 3. (PR. 51).

Staurodoras mojsisovisci Haeckel, E., 1887, p. 168.

Staurodoras mojsisovisci Rüst, J., 1885, p. 22, Plate xxix, Fig. 11.

Haeckel (p. 168) says four crossed spines, 3-sided pyramidal, with three smooth edges. These edges were originally described by Dunikowski (1892) as " inner canals " of the spines. They are present in the Oman examples.

Distribution. Lower (Alpine) Lias, Schafberg near Salzburg, Koprolithen of Iselde (Lias to Albian), Upper Jurassic, Hawasina Chert Series, Oman.

STAURODORAS cf. *RHOMBEA* **RÜST 1898**

Plate 7, Fig. 4. (PR. 51).

Has a smaller central capsule than Rüst's species from the Kieselkalk of Cittiglio.

Distribution. Hauterivian, Cittiglio and Hawasina Chert Series, Oman.

STAURODORAS HAWASINAENSIS sp. nov.

Plate 7, Fig. 5.

Holotype : (PR. 50).

Diagnosis. A *Staurodoras* with concave sides to the shell.

The central shell is a spongy mass, the four crossed spines are poorly developed. The chief character distinguishing it from known forms of *Staurodoras* is the deflated appearance of the sides of the shell.

Measurements. Shortest width between opposite sides of the shell, 0.16 mm.

Distribution. Hawasina Chert Series, Oman.

STAURODORAS LEHNERI sp. nov.

Plate 7, Fig. 6.

Holotype : (PR. 52).

Diagnosis. A *Staurodoras* with stout spines or rays, its centre a small globular spongy mass.

Measurements. Width of central shell, 0.14 mm. Diameter, tip to tip of spines, 0.80 mm.

Distribution. Hawasina Chert Series, Oman.

FAMILY : DISCOIDAE.

GENUS : *TRIPOCYCLIA* HAECKEL 1881

TRIPOCYCLIA sp. cf. *TRIGONUM* **RÜST 1885**

Plate 7, Fig. 7. (PR. 53).

The present example is without the cellular lattice shown in Rüst's figure. There can be no doubt that Rüst's figures are in a large degree idealised.

Distribution. Jurassic cherts and jaspers of Switzerland, Aptychen Schiefer of Urschlau, Berriasian (basal Neocomian), Hawasina Chert Series, Oman.

TRIPOCYCLIA sp.

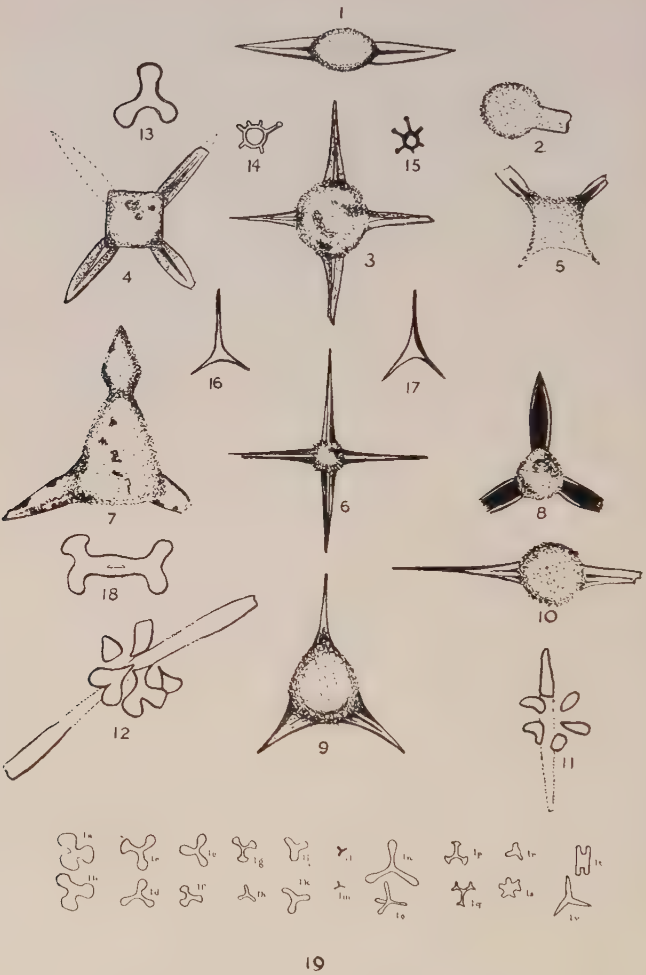
Plate 7, Fig. 8. (PR. 54).

A single example with a much smaller central capsule, Hawasina Chert Series, Oman.

TRIPOCYCLIA sp.

Plate 7, Fig. 9. (PR. 55).

Has much slighter and finer rays than *T. trigonum* Rüst, the triangular central shell is also more spherical.



Radiolaria from the Mesozoic of Oman.

GENUS : *SPONGOLONCHE* HAECKEL 1881

SPONGOLONCHE sp.

Plate 7, Fig. 10. (PR. 51).

A poorly preserved example has been noted ; Hinde (1908, p. 707) records an allied form from the Trias of the Dutch East Indies. Hawasina Chert Series, Oman.

SUBCLASS : ACANTHOMETRA
ORDER : ACANTHARIA
FAMILY : MEYENELLIDAE fam. nov.

GENUS : *MEYENELLA* gen. nov.

Diagnosis. Spicule-like remains with three or more, rarely four, arms or rays, simple, radiating from a common centre. The rays may be of an even thickness and rounded at the ends, club shaped or terminating in rounded knobs.

Measurements. At widest points varying from 0.035 mm. to 0.08 mm. Test or capsule unknown.

Genotype : *Meyenella meyeni* sp. nov.

MEYENELLA MEYENI sp. nov.

Plate 7, Figs. 13 and 19a–q.

Holotype : (P. 28149), Jurassic, Pepanai Island, Central Borneo. Selected from among G. J. Hinde's described material preserved in British Museum (Natural History) collections.

Synonomy :

Spicule ind. Pantanelli, D., 1880, p. 57, Figs. 51 and 53 pars.
Sphaerozoum sp. Rüst, J., 1885, p. 284, Plate 1, Figs. 2 pars. 2a, 2b, 2c, 2e, 2f, 2g. Non Figs. 1, 2d, 2h, 2i.
Sphaerozoum sp. Rüst, J., 1888, p. 190.
Sphaerozoum sp. Parona, C. F., 1890, p. 146, Plate 1, Fig. 1.
Sphaerozoum spec ? Rüst, J., 1892, p. 132, Plate viii, Fig. 11.
non Sphaerozoum ? Parona, C. F., 1895, p. 130, Plate 1, Figs. 1 and 2.
Sphaerozoum sp. Hinde, G. J. and Fox, H., 1895, p. 634.
Sphaerozoum spec ? Rüst, J., 1898, p. 4.
Sphaerozoum sp. Vinassa, de Regny, P. E., 1898, p. 218.
Sphaerozoum sp. Hinde, G. J., 1899, p. 9, Plate 1, Figs. 1a–1q.
Sphaerozoum sp. Hinde, G. J., 1899, p. 43, Plate viii, Figs. 1a–1e.
non Sphaerozoum sp. Neviani, A., 1900, p. 656, Plate 9, Fig. 33.
Sphaerozoum sp. Hinde, G. J., 1908, p. 700, Plate v, Figs. 1a–1i.

Formae incert. sed. ("*Sphaerozoum*") Tan Sin Hok, 1931, p. 95.
Sphaerozoum sp. Sykowski, Z., 1932, p. 163, Plate viii, Fig. 2.
Sphaerozoum sp. Davis, A. G., 1947, p. 178, Figs. 2, 3a–e.
Sphaerozoum sp. McCallien, 1947, p. 180, Fig. 3, Plate i, Fig. 1.
Sphaerozoum sp. Davis, A. G., 1949, p. 12, Figs. 4c–f.

Diagnosis : As for the genus.

Description and Remarks.

The test is unknown, only skeletal remains consisting of free spicule-like shapes or bodies now occurring detached in radiolarites or radiolaria bearing rocks. Their forms are variable but generally conform to a Y-shaped pattern with or without expansions at the extremities. The latter are variable and may be obtuse or club shaped, expanded or divided. The shanks forming the Y may be suppressed giving the object a trefoil shape ; further, the shanks may dichotomise giving an H shape, this latter form being much rarer. All examples seem to be in a single plane and very thin.

Meyen's genus *Sphaerozoum* (1834, p. 163) is monotypic and was proposed for one of the few known genera of colony-building radiolaria—pelagic forms of the China seas. An important structural feature of this genus is the presence of abundant geminate needle shaped spicules dispersed round the outer part of the cellular capsule or forming a protective zone at the periphery. Spicular bodies here described as *Meyenella* do not occur in any known species of Recent *Sphaerozoum* although palaeontologists have in the past included them in this genus. *Meyenella* has a much stronger resemblance to the apophyses attached to the radial spines of *Acanthometra* and allied genera. Unfortunately an example showing the supposed apophyses in conjunction with radial spines has not been observed. It is more convenient to place these fossils in a new genus than to continue to regard them as belonging to *Sphaerozoum*.

Butschli (1906, p. 784) discovered that the skeleton of Acantharia consisted of strontium sulphate as distinct from silica or acanthin which composes the skeleton of the majority of radiolaria. In respect of *Meyenella* it is interesting to note that Hinde (1899, p. 9) states, "These spicules have all a glistening white appearance in transmitted light, quite distinct from that of ordinary radiolarian tests".

Provisionally *Meyenella* is here placed with *Acanthometra* for the following reasons : the general appearance has such a strong resemblance to the apophyses of the *Acanthometra* (see Müller 1858 and Popofsky 1904), and the suggestion that the original chemical constitution was other than silica or acanthin, possibly strontium sulphate as in Recent *Acanthometra*.

The generic and specific names are chosen as a tribute to Prof. F. J. F. Meyen[1], the discoverer of living radiolarians in 1834.

Distribution. Radiolarites from Devonian to Upper Cretaceous, rare in the Devonian, occurrences gradually increasing upwards into the Triassic: most abundant in the Jurassic, becoming rarer in the Cretaceous. Its presence in the Tertiary is not recorded with any certainty. Found in Europe, Carboniferous to Jurassic; Asia, Triassic to Upper Cretaceous; Australia, Devonian only. It occurs in half the samples examined from the Hawasina Series of Oman.

MEYENELLA ROTULA sp. nov.

Plate 7, Figs. 14 and 15.

Holotype. (PR. 57).

Diagnosis. Radiate spicular forms consisting of a central portion throwing off six radial arms.

Associated with radiolaria in radiolarites are sundry flat spicular bodies which have been recorded as *Sphaerozoum* sp.

They are wheel-shaped but without a tyre, with a central hub with usually six rays or spokes. The following examples appear in the literature:

Sphaerozoum sp. Rüst, J., 1885, p. 284, Plate I, Fig. 2, (central figure). Lias of Iselde.

Sphaerozoum sp. Rüst, J., 1885, p. 284, Plate I, Figs. 2h and 2i. Tithonian jaspers of the Tyrol and West Switzerland.

Sphaerozoum sp. Neviani, A., 1900, p. 656, Plate IX, Fig. 33. Mesozoic of Bologna.

Sphaerozoum sp. Hinde, G. J., 1899, a very stunted form, p. 9, Plate I, Fig. 1s. Jurassic cherts of Central Borneo.

Two examples have been discovered in the Hawasina Series.

Measurements. Width, including rays, 0.40–0.60 mm.

? *MEYENELLA HENSONI* sp. nov.

Plate 7, Figs. 11 and 12.

Holotype: FH/1441/2B. Iraq Petroleum Company, London collections. Jurassic, Garna, Syria.

Diagnosis. Central capsule composed of radially disposed Y-shaped wings or spicules. Polar rays, two only.

The writer is indebted to Dr. F. R. S. Henson of the Iraq Petroleum Company, London, for facilities for studying a series of radiolarites from a number of localities in the Middle East. Among this material a form which reveals the " wings " or spicules in conjunction with the polar rays has been discovered. The spicules are not quite the same shape as typical *Meyenella* being lanceolate and the attachment area is attenuated and stalk-like. The polar rays, with a north and south orientation, are long in proportion to the capsule. The total number of spicules composing the test cannot be ascertained, the thin sections available show a group of five in all instances.

---

[1] Franz Julius Ferdinand Meyen, 1804–40. Born at Tilsit. Trained and practised as a physician 1826. Undertook voyage to South Seas for A. von Humboldt and returned with large collections, 1830–2. Professor of Botany, Berlin, 1834 (*Flora*, 1845, p. 618). His *Outlines of the Geography of Plants*, 1836, was issued as a translation by the Ray Society in 1846.

GENUS : *PALAEACANTHUS* gen. nov.

Diagnosis. Forked spicules with sharp points, Y- or H-shaped. Test or capsule unknown.

Measurements. 0.13 mm. in diameter.

Genotype : *Palaeacanthus spinosus* sp. nov. Jurassic, Central Borneo.

PALAEACANTHUS SPINOSUS sp. nov.

Plate 7, Figs. 16 and 17.

Holotype : (PR. 58).

Synonomy :

Spicule ind. Pantanelli, D., 1880, p. 57, Fig. 53 *pars*.
Sphaerozoum sp. Rüst, p. 284, 1885, Plate I, Figs. 1 and 2 *pars*.
Sphaerozoum sp. Hinde, 1889, p. 9, Plate I, Fig. 1v.
Sphaerozoum sp. Hinde, 1908, p. 700, Plate V, Fig. li.

Diagnosis. As for the genus.

Spicules of this type and of *Meyenella* were previously included by palaeontologists with *Sphaerozoum* Meyen.

Distribution. Jurassic radiolarites of Tuscany, Switzerland, Central Borneo ; Lower Lias of the Tyrol ; Triassic of the Dutch East Indies, and the Hawasina Chert Series of Bait al Falaj, Muscat, Oman.

CLASS : NASSELLARIA
ORDER : CYRTELLARIA
SUBORDER : CYRTOIDEA
FAMILY : LITHOCAMPIDAE

GENUS : *LITHOCAMPE* EHRENBERG 1838

LITHOCAMPE sp. indet.

Only one example was found in the Hawasina Chert Series of Oman.

List of Radiolaria from the Hawasina Series, Oman.

Cenosphaera spp.
Ellipsidium sp.
Xiphosphaera sp.
Cenellipsis cf. *monoceros* Rüst, 1885.
Staurodoras mojsisovisci Dunikowski, 1882.
Staurodoras cf. *rhombea* Rüst, 1898.

Staurodoras hawasinaensis sp. nov.
Staurodoras lehneri sp. nov.
Tripocyclia cf. *trigonum* Rüst, 1885.
Tripocyclia sp.
Tripocyclia sp.
Spongolonche sp.
Meyenella meyeni gen. et sp. nov.
Meyenella rotula sp. nov.
Palaeacanthus spinosus gen. et sp. nov.

AGE OF THE HAWASINA SERIES

The most characteristic forms present in the Hawasina Cherts are *Meyenella meyeni*, *Cenellipsis monoceros*, *Staurodoras mojsisovisci*, *S. rhombea* and *Tripocyclia trigonum.*

The first three species are typically Jurassic but may occur rarely in the Lower Cretaceous ; the remaining species are not found above the Neocomian. The evidence suggests that the Hawasina Series represent a transitional phase from Upper Jurassic to Lower Cretaceous (Tithonian—Neocomian).

REFERENCES

Bütschli, G. 1906. Chemische Natur der Skelettsubstanz der Acantharia. *Zool. Anzieger*, 30, pp. 784–9.

Davis, A. G. 1947. In McCallien, W. J. A note on the Devonian Kieselschiefer of the Bosphorus. *Rev. Fac. Sci. Universite d'Istanbul* 12. Ser. B, pp. 173–81.

———. 1949. In Bailey, E. B. Notes on the Geology of the Elburz Mountains North-East of Tehran, Iran. *Quart. Journ. Geol. Soc.*, 104, pp. 1–42.

Dunikowski, E. 1892. Die Spongien, Radiolarien und Foraminiferen der Unterliassischen schichten von Scafberg bei Salzburg. *Denk. k. Akad. Wiss.* Wien. Bd. 45, 1882, pp. 163–94, Plates 1–6.

Ehrenburg, G. 1839. Polycystina in Uber die Bildung der Kreidefelsen und des Kreidmergels durch unsichtbare Organismen. *Abh. k. Akad. Wiss.*, Berlin, pp. 59–147.

———. 1854. Mikrogeologie. Leipzig.

Glaessner, M. F. 1945. *Principles of Micropalaeontology.* Melbourne and London.

Gray, K. W. 1949. A tectonic window in South-Western Iran. *Ab. Proc. Geol. Soc. London.* No. 1449, pp. 58–60.

Haeckel, E. 1862. Die Radiolarien. Eine Monographie. Berlin.

———. 1881. Prodromus Systematis Radiolarium. *Jenaische Zeitschr. fur Naturw.*, Bd. 15, pp. 418–72.

———. 1887. Report on the Scientific Results of the Voyage of H.M.S. *Challenger* : Zoology Vol. 18—Report on the Radiolaria. London.

Henson, F. R. S. 1949. A Synopsis of the Stratigraphy and Geological History of Cyprus. *Ab. Proc. Geol. Soc. London*, pp. 46–50.

Hinde, J. G. 1899. On the Radiolaria in the Devonian Rocks of New South Wales. *Quart. Journ. Geol. Soc.*, 55, pp. 38–64.

———. 1899. Description of Fossil Radiolaria from the rocks of Central Borneo obtained by Prof. G. A. F. Molengraaff in the Dutch Exploring Expedition of 1893–4, pp. 1–56. Plates 1–4. In Molengraaff, G.A.F.

1899, Borneo Expedition. Geological Explorations in Central Borneo (1893–4). English edition.

HINDE, J. G. 1908. Radiolaria from Triassic and other rocks of the Dutch East Indian Archipelago (in Verbeek D.M. Report on the Geology of the Moluccas). *Jaarb. Mijn. Ned. Oost—Indie* 37, pp. 694–736. Plates 5–10.

HINDE, J. G. and H. FOX. 1895. On a well marked Horizon of Radiolarian Rocks in the Lower Culm Measures of Devon, Cornwall and West Somerset. *Quart. Journ. Geol. Soc.*, 51, pp. 609–68.

KIRCHLEGER, F. 1845. Flora oder Allgemeine botanische zeitung. Regensburg. 28, p. 618.

LANKESTER, E. R. 1909. A Treatise on Zoology, London.

LEES, G. M. 1928. The Geology and Tectonics of Oman and of parts of South-Eastern Arabia. *Quart. Journ. Geol. Soc.*, 84, pp. 585–670.

MCCALLIEN, W. J. 1947. See Davis, A. G., 1947.

MEYEN, F. J. F. 1834. Uber das leuchten des Meeres und beschreibung einiger polypen und anderer niederer Theire. *Nova. Act. Acad. Caesa Leopold. Carol, Nat. Cur.*, 16, pp. 127–58.

MOROFF, T. and G. STIASNY. 1909. Uber Bau und Entwichlung von Acanthometron pellucidum J.M. *Arch. Protisk.*, 16, pp. 209–57.

MÜLLER, J. 1858. Uber die Thalassicollen, Polycystinen und Acanthometren des Mittelmeeres. *Abh. k. Akad. Wiss.* Berlin, pp. 1–62, Plates I–XI.

NEVIANI, A. 1900. Supplemento alla fauna a Radiolari delle Rocce Mesozoiche del Bolognese. *Boll. Soc. Geol. Ital.*, 19, pp. 645–56.

PANTANELLI, D. 1880. I diaspri della Toscana e i loro fossili. *Atti dei Lincei.*, 8, Ser. 3, pp. 35–65.

PARONA, C. F. 1890. Radiolarie nei nodule selciosi del calcare guirese de Cittiglio presso Laveno. *Boll. Geol. Soc. Ital.*, 9, pp. 132–75.

PARONA, C. F. and G. ROVERETO. 1895. Diaspri permiana a radiolarie de Montenotte. (Liguria Occidentale). *Atti. R. Accad. Sci. Torino*, 31, pp. 123–37.

POPOFSKY, A. 1904. Die Acantharia der Plankton Expedition. *Ergeb. Plank Exped.* Pt. 1, pp. 1–158.

RÜST, J. 1885. Beiträge zur Kenntniss der fossilen Radiolarien aus Gesteinen des Jura. *Palaeontographica*, 31, pp. 273–321.

————. 1888. Beiträge zur Kenntniss der fossilen Radiolarien aus Gesteinen der Kreide. *Palaeontographica*, 34, pp. 181–213.

————. 1892. Beiträge zur Kenntniss der fossilen Radiolarien aus Gesteinen des Trias und der Palaeogoischen Schichten. *Palaeontographica*, 38, pp. 107–200.

————. 1898. Neue Beiträge zur Kenntniss der fossilen Radiolarien aus Gesteinen des Jura und der Kreide. *Palaeontographica*, 45, pp 1–67.

SCHEWIAKOFF, W. 1902. Chemische Natur der Skelette der Radiolarien Acanthometrea. *Zeitschr. Naturw.* (Halle), 75, pp. 239–240.

SUJKOWSKI, Z. 1932. Radiolarites des Karpates Polonaise Orientalles et leur comparison Radiolarien de la Tatra. *Bull. Serv. Geol. Poland.*, 7, pp. 97–168.

TAN SIN HOK. 1931. Discoasteridae, Coccolithinae and Radiolaria. *Leidsche Geol. Meded.*, 5, pp. 92–114.

VINASSA DE REGNY, P. E. 1898. I Radiolari delle ftaniti Titoniane di Carpena (Spezia). *Pal. Italica.*, 4, pp. 217–38.

EXPLANATION OF PLATE 7

Fig. 1. *Xiphosphaera* sp. X 60.
,, 2. *Cenellipsis* sp. cf. *monoceros* Rüst. X 50.
,, 3. *Staurodoras mojsisovisci* Dunikowski. X 70.
,, 4. *Staurodoras* sp. cf. *rhombea* Rüst. X 60.

Fig. 5. *Staurodoras hawasinaensis* sp. nov. Holotype. X 50.
,, 6. *Staurodoras lehneri* sp. nov. Holotype. X 50.
,, 7. *Tripocyclia* sp. cf. *trigonum* Rüst. X 80.
,, 8. *Tripocyclia* sp. X 70.
,, 9. *Tripocyclia* sp. X 100.
,, 10. *Spongolonche* sp. X 40.
,, 11. *Meyenella hensoni* sp. nov. X 100.
,, 12. *Meyenella hensoni* sp. nov. Holotype. X 100.
,, 13. *Meyenella meyeni* gen. et. sp. nov. X 150.
,, 14. *Meyenella rotula* sp. nov. Holotype. X 50.
,, 15. *Meyenella rotula* sp. nov. X 50.
,, 16. *Palaeacanthus spinosus* gen. et sp. nov. X 100.
,, 17. *Palaeacanthus spinosus* gen. et. sp. nov. Holotype. X 100
,, 18. Apophyse of an Acantharia, after Popofski 1904, Plate 2, Fig. 7c, p. 154. X 180.
,, 19. Reproduction of Hinde's original figures of *Sphaerozoum* sp. X 100. Jurassic, Central Borneo. *Meyenella meyeni* sp. n. shown in 1a–q. Holotype, 1e.

Figs. 1–10 and 13–17. Hawasina Series, Bait al Falaj, Oman.
,, 11 and 12. Jurassic, Garna, Syria.

FIELD MEETING TO CHARLTON, PLUMSTEAD AND ABBEY WOOD

Saturday, 25th June, 1949

Report by the Director : F. J. Epps, F.G.S.

[*Received 2nd November*, 1949]

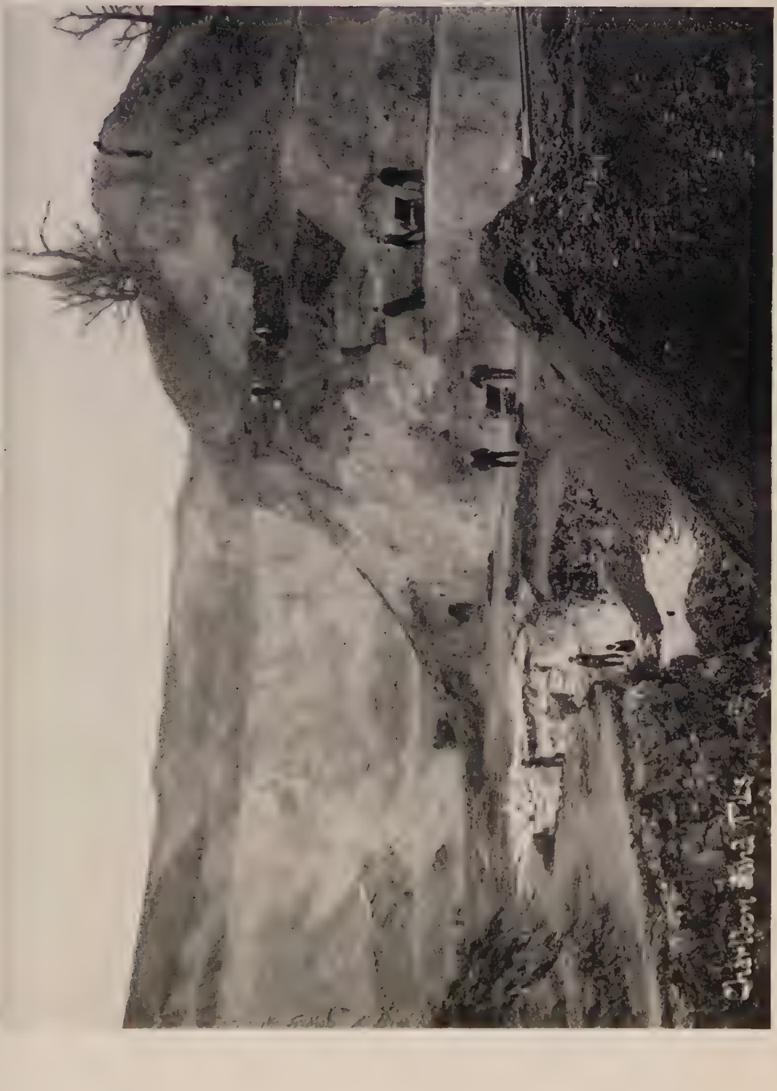
A PARTY of 27 attended the meeting, the object being to give members an opportunity of visiting and collection from classic sections in the Lower London Tertiaries. It was a replica of the meeting conducted by W. S. Pitcher, B.Sc., F.G.S., and his report and references in *Proc. Geol. Assoc.*, 59, 1948, pp. 172–3, will serve as the report for this meeting. At the conclusion of the meeting, the President thanked the Director for his services.

Plate 8, from a photograph taken in 1906, is published as an interesting record of Charlton Sand Pit.

EXPLANATION OF PLATE 8

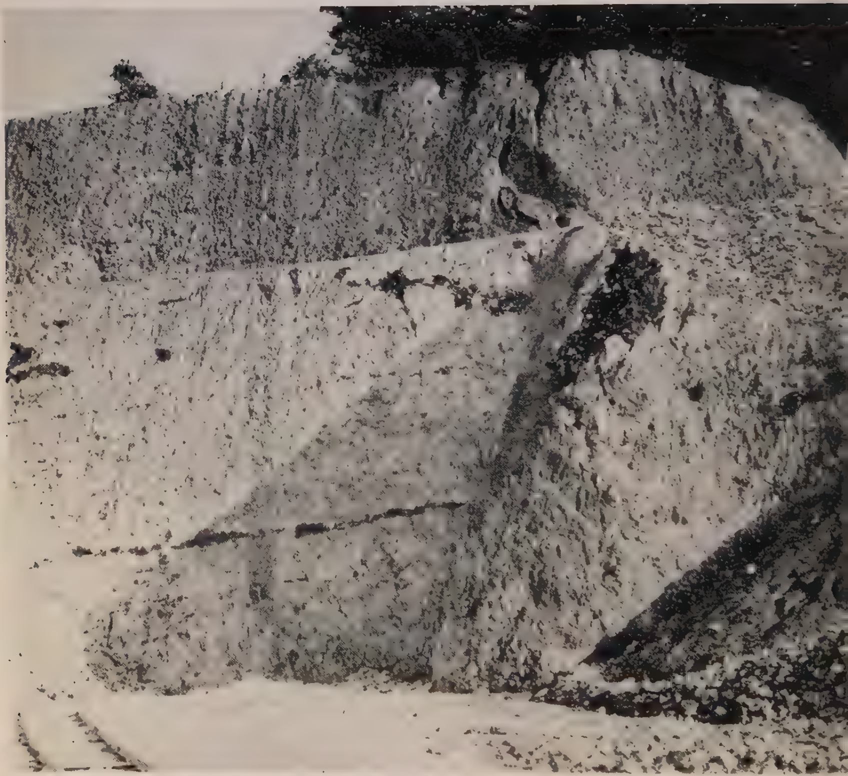
Photograph of Charlton Sand Pit taken in 1906. The Upper Chalk is seen in the cutting in the bottom of the working pit, and above the Thanet Sand the darker exposure consists of the Woolwich and the Blackheath Beds. The succession is as follows :—

Blackheath Beds	Ypresian
Striped Loams	Upper
Woolwich Shell Bed	Landenian
Woolwich Bottom Bed	Lower
Thanet Sand	Landenian
Upper Chalk and " Bull-head " Bed.	



Photograph of Charlton Sand Pit taken in 1906.

[*To face p.* 218.



View of the Northern face of the Castle Lime Works, South Mimms, showing severa
sheet pipes. The buttress on the right, which is now hidden behind tip, consists of
vertical pipe of light coloured sand, almost indistinguishable in the Plate, from chalk

To face p. 219.]

SOLUTION OF THE CHALK IN THE MIMMS VALLEY, HERTS.

by J. F. KIRKALDY, D.Sc., F.G.S.

[*Demonstrated in the field Saturday*, 28*th May*, 1949]
[*Received* 17*th September*, 1949]

SUMMARY.—Solution phenomena, consisting of vertical, oblique, and horizontal pipes infilled with Eocene sand, flints, and fragments of chalk are described. Examination of the Mimms Valley has shown that swallow-holes are even more abundant than was formerly supposed. The reasons for the exceptionally localised solution of the Chalk in the area are briefly discussed.

IN a previous communication [6*] S. W. Wooldridge and the writer drew attention to certain features of the Mimmshall Brook. This brook and its tributaries rise at or near the base of the spreads of gravel capping the broken ring of high ground extending from Brookmans Park, past Potters Bar, Barnet, and Arkley, to Shenley. They flow across the outcrops of the London Clay and Reading Beds and then, when they reach the Chalk around South and North Mimms, disappear underground to feed the springs, about ten miles distant, along the valley of the River Lea near Hertford. In pre-Chalky Boulder Clay times the Mimmshall Brook flowed northwards through Marshmoor (Fig. 1) to join the River Lea near Hatfield, but when this valley was blocked by the advancing Chalky Boulder Clay ice, the stream cut a channel along the ice margin and was diverted to join the River Colne near Colney Heath. After exceptionally heavy rains today the swallow-holes at Water End are unable to take all the discharge and then, for a short time, the old channel to the Colne is in use once more.

But these are not the only features of interest of this small brook. The reopening, shortly before the war, of the chalk pit on the south side of the Castle Mound, 1 mile north-north-east of South Mimms (National Grid reference 52/230025) has produced a magnificent exposure for studying the effects of solution of the Chalk beneath a thin cover of Tertiary beds.

THE CASTLE LIME WORKS

This section now shows up to five feet of the ferruginous fine sands of the Reading Beds with a typical development of the " Bull Head Bed " at their base, overlying some fifty feet of Chalk referable to the lower part of the zone of *Micraster coranguinum*. The pit is worked in three levels. The overburden of Eocene sands is stripped off for some yards ahead of a twenty-foot face of Chalk, which is separated by a broad bench carrying a tramway from a lower working face. The higher Chalk face is kept vertical throughout most of its length, but the lower face is sloped at about sixty degrees and the

---

* For list of References, see p. 223.

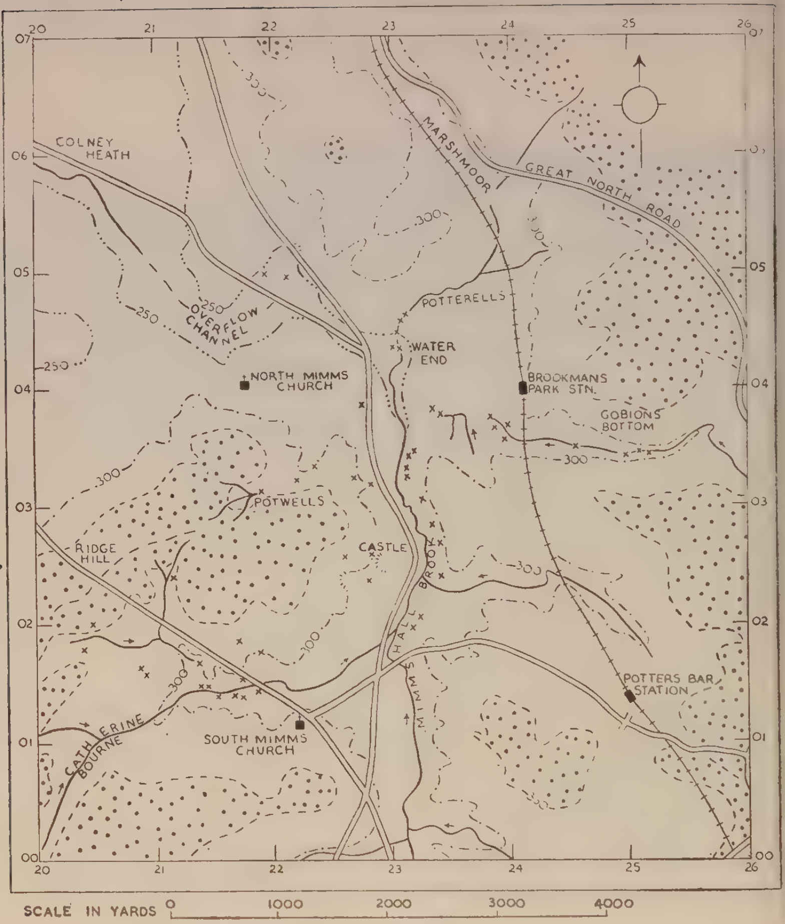
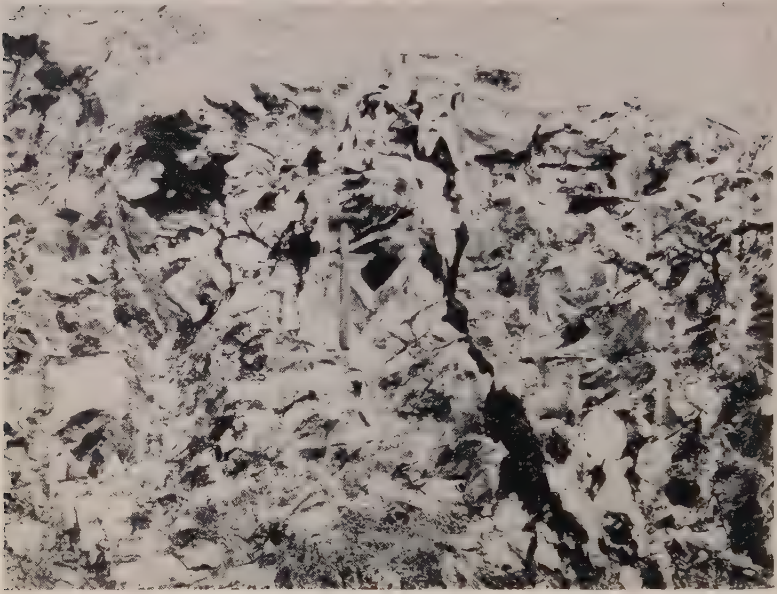
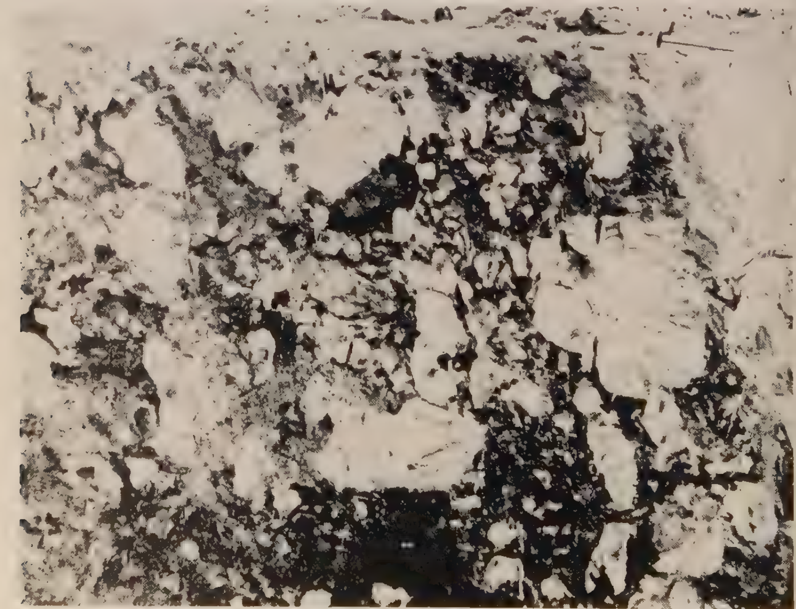


FIG. 1.—SKETCH MAP OF THE VALLEY OF THE MIMMSHALL BROOK. Ground above 350 feet O.D., stippled; crosses mark the site of swallow-holes.

chalk, loosened by pick and crowbar, slides down to the floor of the pit, round which low vertical faces are maintained. This method of working means that clean faces can be studied along the upper face, but that in the lower, and generally more interesting part of the quarry, one is often restricted to the vertical faces along the base and to the side faces. Unfortunately the high side faces are being steadily hidden as working proceeds behind great heaps of unwanted flint and sand.



A.—The intricate veining of the chalk by Tertiary sand and clay, 60 feet below the general Chalk-Tertiary Junction.



B.—Blocks of chalk of varying size and angularity set in dark coloured sand and clay. Both photographs show parts of the side of the trial hole, 60 feet below the general Chalk-Tertiary Junction, in the Castle Lime Works, South Mimms.

To face p. 221.]

The separation of the Tertiary beds and the Chalk is not however nearly so clean-cut as is suggested above. Not only are the Eocene sands piped into the Chalk in the manner with which one is familiar in scores of sections, the largest vertical pipe noted being thirty-three feet in diameter at the bottom of the pit ; but particularly in the lower face, the Chalk is veined and seamed with Tertiary material. Thin seams of dark chocolate clay cut through the Chalk at all angles and where these films widen out to more than about an eighth of an inch in thickness, they contain some yellow sand. Very conspicuous are the horizontal lenses or to use a term suggested by Mr. F. H. Edmunds, the " sheet pipes " of sand and clay, some traceable for only a few yards, others for as much as fifty yards and reaching a maximum thickness of two to three feet (Plate 9). All the larger pipes, whether vertical, oblique, or horizontal, contain scattered flints, either unworn or typical glauconite stained " Bullheads " or well-rounded " Tertiary pebbles ", together with numerous fragments of chalk, ranging in size from granules to blocks of a cubic foot or more.

The margins of the pipes are usually clean with often a film of slickensided clay along the edge of the Chalk, but at intervals both along the vertical pipes and more commonly on the upper surface of the sheet pipes, the relation of Chalk and Tertiary material is a most intricate one, with veins and fingers of sand extending for a foot or more, first completely round and then just along the divisional planes between blocks of chalk (Plate 10). These contacts recall very strongly to mind the arrested stoping of gabbro by granite so clearly seen in the cliffs of Ronez, Jersey [see **3**, Fig. 15, p. 188], for there are the same " frozen blocks " and same outer zone of veins, but this analogy must not be taken too far, for there is no evidence of assimilation, the chalk " xenoliths " having clean-cut margins with no surface staining or alteration. Whilst the quarry has been under observation, this veining of the Chalk and the sheet piping have always been best developed on the lower face, that is between twenty and fifty feet below ground level.[1] In the upper face vertical or slightly oblique pipes have been the rule, though very occasionally horizontal developments have been noted.

This section therefore affords an exceptional opportunity for studying the effects of solution of the Chalk. In the main, it is the vertical joints that have been enlarged to produce the vertical or slightly oblique pipes, but at numerous levels, which are usually not related to marl or flint seams, the obvious divisional planes in the Chalk, sheet piping has been developed. The angular fragments and blocks of chalk now embedded in the sandy matrix of the wider parts of the sheet pipes are clearly pieces that have fallen from the roofs of the miniature caverns that were produced, for saturated Chalk has little strength. For even the smallest fissures in the chalk around the pipes to be so completely filled with Tertiary material there must have been a considerable and fairly fast moving flow of water through all the channels. It therefore seems reasonable to regard this quarry as exposing a section through a group of fossil swallow-holes similar to those now functioning at Water End. Unfortunately it is impossible, under present conditions, to descend the active swallow-holes and see if sheet piping is developed in their sides.

---

[1] Since this communication was written, a fresh hole has been sunk in the floor of the pit. This shows that the piping extends downwards for a further ten feet. In the main pipe exposed there is an exceptionally fine development of chalk " xenoliths " in a matrix which is more clayey than at higher levels; unfortunately this section is being filled up with tip.

Mr. R. Butler has kindly lent photographs and papers, which were exhibited at a previous Field Meeting [**2**, p. 189] of three different swallow-holes which subsided during the year 1928. The one most thoroughly investigated, proved to be thirty-six feet in depth, with a diameter at the surface of twenty-two feet, narrowing rapidly downwards to just sufficient space for a man to descend an almost vertical ladder. Such a swallow-hole, when filled with debris, would be comparable in size to the larger vertical pipes now exposed at the Castle Lime Works. Unfortunately the photographs do not show clearly the detail of the sides of the swallow-holes.

OTHER EVIDENCE OF SOLUTION IN THE MIMMS VALLEY

Water End and the Castle Lime Works are not the only places in the Mimms Valley where solution has been active. Unfortunately the Castle Lime Works give the only good section of Chalk. There are a number of other chalk pits, but with one exception they are thoroughly degraded and do not seem to have been fully described when they were in work. In a pit, 500 yards to the southwest of the Castle Mound and now being rapidly filled up with refuse, there are some low sections of strongly piped Chalk showing veining and suggestions of sheet piping.

Another indication of solution is given by the swallow-holes in the sides and floor of the valley. In the past Whitaker [**4**] has recorded a number of groups at Gobions Bottom (52/250034), near Potwells (52/219031), in the Catherine Bourne by the County bounpary (52/214015) and near Mymms Hall (52/233020), whilst in the previous communication a map [**6**, Fig. 27, p. 309] showed the great number near Water End. But all these swallow-holes are either in or very near the beds of the existing streams and attention does not seem to have been paid to those at higher levels. On Fig. 1 are shown all the swallow-holes that can be detected today, including one that has produced the characteristic depression on the surface a few yards from the Chalk face of the Castle Lime Works. Whilst it is possible that a few of the depressions shown on the Figure may have a different origin, there can be no question that swallow-holes occur at numerous intervals all along or even slightly above the Chalk–Tertiary boundary and are to be found more irregularly on the valley sides below this, whilst there is a second concentration along the present valley bottom, where they are more easily detected.

It is interesting to note that one effect of the War Land Drainage Campaign has been to increase considerably the flow of the Mimmshall Brook. Between April and July 1936, 11.24 inches of rain were recorded at Potters Bar, the rainfall recording station nearest to North Mimms. This year (1949) the total for the same four months was 5.32 inches, yet in 1936 the bed of the Mimmshall Brook was often dry for long distances above Water End. This year on every visit there has been a steady flow of water down to one or other of the swallow-holes of the Water End group, so that despite an exceptionally dry summer, it would have been impossible to have carried out such a thorough survey of the stream bed as was done in 1936.

Woodland has recently written : " It is reasonable to assume that originally the Chalk had more or less uniform permeability, but as topographical evolution develops . . . selective differentiation [of permeability] took place " [**5**, p. 47]. The events that have produced such an exceptional development of piping in the Chalk of the Mimms Valley have been indicated in our previous account [**6**, p. 308] of the geological history of the area. They are briefly the gentle doming of the Chalk during the mid-Tertiary folding and the breaching of the Tertiary cover of the dome at an exceptionally early date by the old Thames, which probably occupied the valley for only a comparatively short time before it was diverted to the south. As a result the " misfit " valley has been enlarged only slowly by the small Mimmshall Brook, with the result that, as in the western or Radlett arm of the old loop valley, rain water, falling on the feather edge of the Tertiary Beds, had an exceptional opportunity to widen the fissures in the underlying Chalk. This would explain the abundance of the vertical and oblique pipes seen in section and of the swallow-holes noted in the fields and woods. The horizontal or " sheet pipes " recall the horizontal sections of the subterranean drainage of the Pennines which have been recently described to the Association in a lecture by Dr. M. M. Sweeting.[1] They are most probably " fossil " water tables beneath what was once an active group of swallow-holes.

The author would like to express his indebtedness to his colleague, D. W. Humphries, Esq., B.Sc., for his assistance in measuring and photographing the Castle Lime Works and to the Barnet Lime Company for facilities granted.

REFERENCES

1. Boswell, P. G. H. 1949. *A Review of the Resources and Consumption of Water in the Greater London Area.* Metropolitan Water Board. London.

---

[1] The substance of this lecture has now been published :— Sweeting, M. M. 1950. Erosion Cycles and Limestone Caverns in the Ingleborough District. *Geog. Journ.*, 115, pp. 63–78.

2. Evans, P. 1944. Field Meeting at Water End, North Mimms, Hertfordshire. *Proc. Geol. Assoc.*, 55, p. 189.
3. Wells, A. K. and S. W. Wooldridge. 1931. The Rock Groups of Jersey. *Ibid.*, 44, pp. 178–215.
4. Whitaker, W. 1921. Water Supply of Buckinghamshire and Hertfordshire. *Mem. Geol. Surv.*
5. Woodland, A. W. 1946. Water Supply from Underground Sources of Cambridge–Ipswich District. Wartime Pamphlet No. 20, Part X. *Mem. Geol. Surv.*
6. Wooldridge, S. W. and J. F. Kirkaldy. 1937. The Geology of the Mimms Valley. *Proc. Geol. Assoc.*, 48, pp. 307–15.

FIELD MEETING AT WATER END, NORTH MIMMS

Saturday, 28th May, 1949

Report by the Director : J. F. Kirkaldy, D.Sc., F.G.S.

[*Received* 17*th September*, 1949]

THE party assembled at Potters Bar Station and then walked by footpaths to the Castle Lime Works, where they were joined by a contingent from Cambridge, bringing the numbers up to twenty-seven. After inspecting the features described in the preceding communication, the party walked along the valley of the Mimmshall Brook to Water End. Owing to the heavy rain of the preceding few days, the brook was discharging underground down to the terminal swallow-hole, whilst the spread of fresh mud on the grass in low lying places near the swallow-holes showed that, at times, the flow of water had been greater than the capacity of the swallow-holes so that a small lake had been formed. On the previous Monday, after a dry spell, the grass had been clean and in the bare patches the muddy soil had been strongly suncracked.

Tea was then taken at an adjacent café and the usual vote of thanks, proposed by the President, enabled the Director, speaking as Secretary for Field Meetings, to thank Mr. E. Evans for undertaking the secretarial work for this Field Meeting and to appeal for more members to help thus in easing the work of Directors.

The party then walked along the pleasant track through North Mimms Park and Hawkshead Wood. The interesting group of swallow-holes near Potwells was indicated, as well as small exposures in the Pebble Gravel and the Reading Beds. On reaching the bus routes at South Mimms, the party dispersed.

TWO BURIED RIVERS—AN AFTERNOON IN LONDON

Saturday, 27th August, 1949

Report by the Director : John F. Hayward, Ph.D., M.Sc., F.G.S.

[*Received 2nd September,* 1949]

ALTHOUGH the holiday season was at its height twenty members assembled at Hampstead Heath Station. From here they climbed the slopes of Hampstead Heath to a point from which, but for the summer haze, they would have had a good view of the Thames Valley. The Director described the geology and topography of the region. He compared it with that at Epping Forest which the Association had visited the previous year.[1] At Hampstead the Claygate and Bagshot Beds were visible but the Pebble Gravel, so extensive in Epping Forest, was here found in small patches only. He then showed how the region was dissected by streams which rose at the base of the sandy Bagshot Beds and the party discovered the valleys of several of these streams which combined to form the River Holebourne, now flowing in pipes.

From Parliament Hill the members travelled by trolley-bus to Farringdon Street, from which point they followed the lower course of the river while the Director gave geological and historical details. At Holborn Viaduct he pointed to a building site which he had been examining on behalf of the Geology Section of the London Natural History Society. This body was responsible for recording temporary geological exposures in the London area and would later produce a full report of this site.[2] It contained alluvial deposits of the River Holebourne resting on an eroded surface of London Clay. At Blackfriars Bridge the party saw the openings through which, in times of flood, the waters of the river discharged into the Thames. At other times the water is diverted into sewers.

After visiting a teashop some of the members walked to the point at which the River Wallbrook entered the Thames and in a similar manner, but in the reverse direction, followed the river to Moorfields where it formerly entered the city.

---

[1] Hayward, J. F. Field Meeting in the Epping Forest District. *Proc. Geol. Assoc.*, 60, 1949, p. 22.

[2] Hayward, J. F. *in* Reports on Temporary Geological Sections in the Society's Area. *London Naturalist*, 29, 1950 for 1949, pp. 36–37.

THE TUBULAR CHALK STACKS OF SHERINGHAM

By T. P. BURNABY

[*Received* 19*th September*, 1949]

SUMMARY.—The tubular stacks described in this paper are shown to be solution-pipes of pre-Weybourne Crag age in the Chalk of North Norfolk, which have been converted into hard tubular structures by secondary lithification due to organic acids. They are associated with a hardened chalk surface crust, beneath the Weybourne Crag, which was formed under sub-aerial conditions at the same time as the tubular stacks. A study of these and other features of the Chalk–Weybourne Crag unconformity has greatly contributed to our knowledge of the conditions prevailing in the area before the incursion of the Weybourne Crag sea.

THE tubular stacks are situated on the beach near the base of the cliff about three-quarters of a mile west of Sheringham (National Grid 146437). When they are not buried beneath the beach pebbles, they are conspicuous objects, rising from the main mass of the Chalk exposed on the beach (Plate 11, A, B). In addition to the main group near Sheringham, there are two solitary tubular stacks, one about half a mile farther west, near the base of the cliff (National Grid 137436), and the other on the foreshore, about halfway between Sheringham and West Runton (National Grid 177434) (Plate 12, B). As far as is known, there are no others in Norfolk, or indeed anywhere in the British Isles, at the present time.*

The tubular stacks have been carved from the Chalk of the coast section by wave-action. The chalk of which the tubular stacks are composed is a limestone which is considerably harder than the ordinary chalk in this area. The stacks assume a variety of shapes : a typical example is roughly cylindrical, with a single central cavity about a foot in diameter. The walls are about three inches thick near the top, becoming thicker towards the base, owing to the tapering of the central cavity. The cavity is usually completely filled with loose beach pebbles.

THE GEOLOGY OF THE COAST SECTION

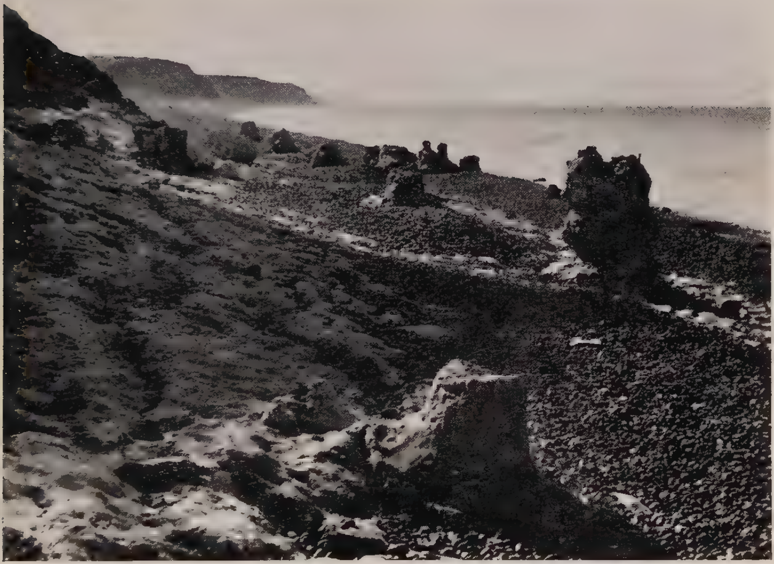
The geology of the North Norfolk coast section has been fully described elsewhere (Reid, 1877 ; Reid and Woodward, 1882†). It may be useful, however, to give a short description here.

We are concerned principally with the unconformable junction of the Chalk and the Weybourne Crag. Apart from one or two dubious inland exposures, the only place where the junction can be studied is on the beach between Weybourne and Cromer. In such a situation, all exposures are of a discontinuous and temporary nature,

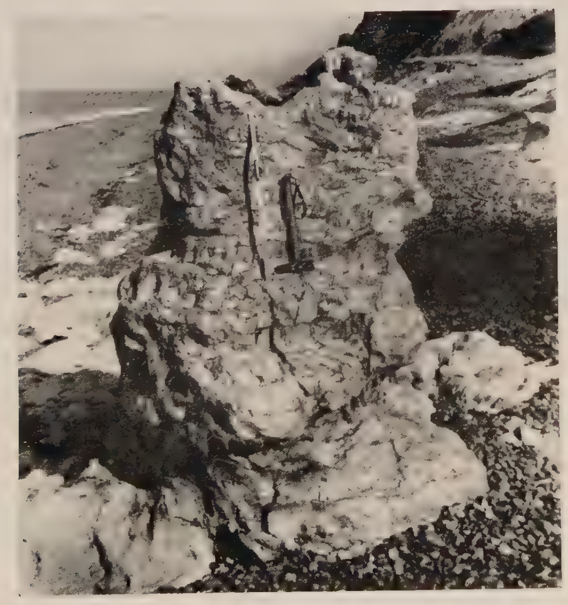
---

* See note at end of paper.

† For list of References, see p. 240.



A.—Tubular chalk stacks near Sheringham



B.—Tubular chalk stack

owing to the shifting beach. In order to examine the section thoroughly, it was necessary to continue observations for several seasons.

Exposures can conveniently be located with reference to the two datum lines provided by the high water mark of *spring* tides (generally, this corresponds in position to the base of the cliff), and the low water mark of *neap* tides (corresponding to the level of the sand-flats of the foreshore). They will be referred to as H.W.M. and L.W.M. respectively.

The succession in the cliff-section is as follows :

Pleistocene :	Glacial drift, etc.	
" Pliocene " (? early Pleistocene)	Cromer Forest Bed Series (fluviatile or estuarine)	Peat, clays, gravels
	Weybourne Crag (marine or deltaic)	Clays, sands, *c.* 15 feet Shelly band, 1–2 feet Ferruginous flint-bed, ½ foot
Upper Senonian	Chalk, zone of *Belemnitella mucronata*	Soft white chalk with flints

The Chalk–Weybourne Crag unconformity is exposed in the cliff about 15 feet above H.W.M. at Weybourne. Traced eastwards, it slopes gradually downwards until at Sheringham it is at H.W.M. At West Runton it descends to L.W.M., and at Cromer it is exposed only at extreme low water of spring tides, and is usually buried beneath the sand-flats. The Chalk itself dips eastwards at about 1 in 70, with the result that the Crag oversteps onto successively higher levels of the Chalk towards the east.

The Crag and Forest Bed together maintain a thickness of 10–15 feet from Weybourne to Cromer, except in places where the Glacial Drift has ploughed through them. The individual beds are very impersistent, seldom extending laterally for more than a few hundred yards. The Crag and Forest Bed facies have been observed to interdigitate at several localities. An exception is the ferruginous basal flint-bed of the Crag, which is almost continuous from Weybourne to Cromer, and probably farther, with only a few local interruptions caused by Forest Bed channels and tongues of Glacial Drift.

The sub-Crag surface of the Chalk is covered with shallow depressions and channels, rarely more than a foot or so in depth. Some, but not all, of these appear to be post-Crag solution effects.

The majority of the Crag fossils occur in drifted beds of separate valves, but a few shells are intact and in position of life. Specimens of *Pholas* have been found in their burrows in the Chalk below the Crag, and leave no doubt as to the latter's marine origin (Reid and Woodward, 1882, p. 11 ; Woodward, 1881, p. 39). It was concluded, largely on the evidence of the *Pholas* burrows, that the basal flint-bed had been produced by the submarine erosion of the Chalk.

The idea that the sub-Crag surface of the Chalk might represent a former land surface was summarily dismissed by Osborne Fisher: "It is hardly possible to conceive submergence to have taken place over so wide an area, without the formation of cliffs, and the consequent entire destruction of the old surface. . . . Moreover, such a sub-aerial condition (of the Chalk surface) would have been accompanied by pipes, which I do not believe exist of that particular date." (Fisher, 1868, p. 546.)

FIELD EVIDENCE RELATING TO THE TUBULAR STACKS

An excavation was made in one of the tubular stacks to determine the shape and depth of the internal cavity, and the nature of the contents (Fig. 1). The cavity contained sand and flints resembling Weybourne Crag material, beneath a cover of clay and pebbles recently washed in by the sea. The cavity was found to be just over three feet deep, measured from the top of the stack. The latter was found to be three feet below the level of the Chalk–Crag junction in the cliff-section opposite, so that when allowance is made for the missing upper part of the tubular stack, it may be inferred that the original cavity was a little over six feet deep. A second excavation was made in another tubular stack, confirming the results obtained from the first excavation.

In August 1947, when I first noticed the tubular stacks, their underground structure could not be observed. In the following April a large boulder of chalk was found lying on the beach below the tubular stacks, with the remains of two of them still attached to one side (formerly uppermost). It became evident that each tubular stack (or close group of two or more) is attached to a large irregularly shaped basal block of hardened chalk (Fig. 2).

The maximum depth to which a typical stack descends into the Chalk is probably about ten feet (i.e. from the Chalk–Crag unconformity to the bottom of the basal block). This is shown by the presence of the detached basal block, completely undercut by wave-action, and by the total absence of tubular stacks in place on the foreshore. The stack near West Runton (Plate 12, B) is the exception that proves the rule, for the reason that the Chalk–Crag unconformity is less than ten feet above L.W.M. at this point.

The walls of the tubular stacks are as hard as marble, and ring under the hammer. We shall see later that this is due to secondary cementation of the chalk with cryptocrystalline calcite. The basal block mentioned above differs, being composed largely of uncemented chalk. The secondary cement has here lithified the chalk only along the sides of the many fissures and joints which traverse the block. The basal block thus owes its resistance to wave-action entirely to a lattice of thin plates of lithified chalk which have formed along the joints. These plates are frequently only 2 mm. thick, one on each

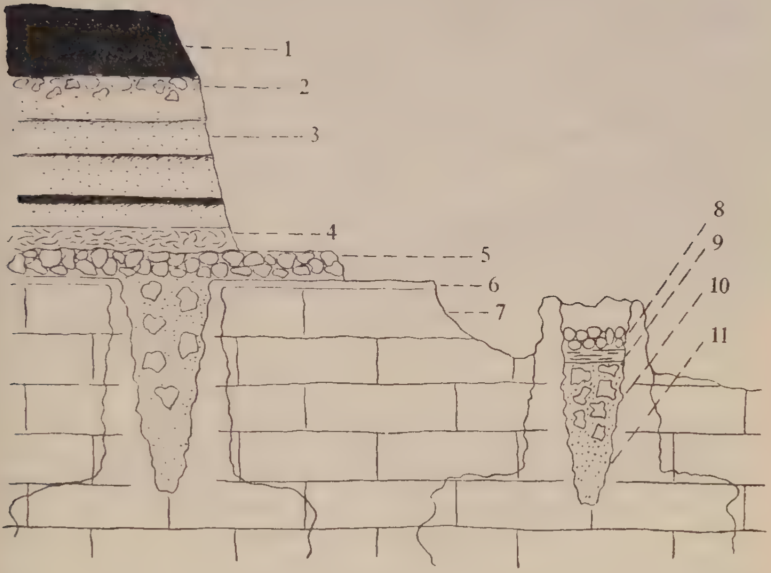


FIG. 1.—Diagrammatic vertical section of tubular stacks.

Cliff-section

1. Glacial drift.
2. Ferruginous gravel at the top of the Weybourne Crag.
3. Weybourne Crag : laminated sands and clay-seams.
4. Shelly band of the Weybourne Crag.
5. Ferruginous basal conglomerate of the Weybourne Crag.
6. Lithified surface crust of the Chalk.
7. Chalk.

Tubular stack

8. Beach-pebbles (recent) ; 6 inches.
9. Grey clay (recent) ; 2 inches.
10. Sand and flints, similar to Weybourne Crag ; 12 inches.
11. Brown sand, similar to Weybourne Crag ; 14 inches.

The diagram is not to scale : the rim of the stack in which the above deposits were found was 3 feet below the level of the surface of the Chalk, the bottom of the cavity was 3 feet 4 inches below the rim of the stack, and the stack itself was 36 feet from the cliff-base.

The probable condition of a tubular stack before exposure is indicated on the left of the diagram.

side of a fissure about 0.5 mm. wide. The fissures themselves may be partly filled with calcite, or with limonite derived from the Weybourne Crag, but they are often empty.

The inner surfaces of the walls of the tubular stacks invariably possess a characteristic roughened texture. They are stained brown

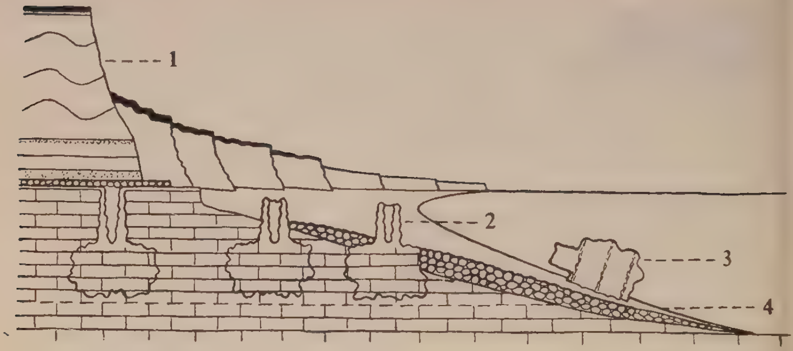


FIG. 2.—Block-diagram of the beach near Sheringham.

1. Cliff-section : glacial drift overlying Weybourne Crag.
2. Tubular stack, projecting through the cover of beach-pebbles.
3. Detached basal block, with remains of tubular stack still attached.
4. Level of former water-table in the Chalk, shown as a dotted line within the Chalk immediately below the bases of the tubular stacks.

N.B.—The diagram is not to scale.

with limonite, but there is never an actual coating of iron-pan. They are full of irregular small cavities, which are usually empty but are occasionally filled with limonite.

THE MODE OF ORIGIN OF THE TUBULAR STACKS

There are several ways in which rock structures with tubular cavities may be produced, and three alternative suggestions which require to be examined are (a) pot-holes, (b) paramoudras, and (c) solution-pipes.

(a) Pot-holes are usually well smoothed internally by revolving stones, whereas the inner surfaces of the tubular stacks are extremely rough. (In this they closely resemble Chalk solution-pipes.) Moreover, pot-holes do not display a marked tendency to form at the intersections of joints, unlike solution-pipes and the tubular stacks.

(b) The paramoudras, or large tubular flint nodules, which are abundant in the Chalk of Norfolk (Woodward, 1881), superficially resemble the tubular stacks, although they rarely, if ever, attain to the size of the latter. The fact that the paramoudras are frequently fractured by joint-planes indicates that they are considerably older than the tubular stacks. Moreover, the stacks are not silicified.

(c) The stacks must therefore have originated as solution-pipes produced by percolating groundwater. (The absence of any reference in the literature to solution-pipes with secondarily hardened walls does not affect this conclusion.) Ordinary solution-pipes are common at the present day in Chalk country (Prestwich, 1855). They also occur in other limestone formations (Day, 1928; Greenly, 1900). The latter paper describes solution-pipes of Carboniferous age. Solution-pipes frequently form in Chalk beneath a cover of soil or gravel; those formerly exposed in the chalk-pit at Lenham were shown to have formed beneath the overlying Tertiary beds (Reid, 1890, p. 45). They descended the full eighty feet of the quarry face to an unknown depth, presumably limited by the water-table or an impervious stratum.

The ten-foot limit to the depth of the tubular stacks near Sheringham suggests that at the time of their formation the water-table in the Chalk was probably about ten feet below the surface (see Fig. 2).

THE PETROGRAPHY OF THE HARDENED CHALK OF THE TUBULAR STACKS

The textures of ordinary and hardened chalk are readily distinguished in hand specimens. The latter possesses a smooth fractured surface of a pale grey colour, unlike the matt texture and white or cream colour of ordinary chalk. The hardened chalk dissolves completely in dilute hydrochloric acid, and its hardness (Mohs' scale) is 3. The rock is therefore not silicified. The porosity is very small and may even be zero in some specimens. This was shown by staining pieces of hardened chalk with an organic dye, and afterwards breaking them across the stain to observe the extent to which the dye had penetrated the rock.

The density of specimens of hardened chalk was measured by two independent methods. First, samples in the form of small chips were measured with a pycnometer, the results obtained ranging from 2·64 to 2·72. The highest value, 2·72, was obtained for a sample which was crushed to powder, and is within the range of values quoted by various authorities for pure calcite (2·710–2·723). Secondly, a small accurately cut cubical block was prepared from a specimen as free from small cavities and inclusions as possible, and its mean density was found by direct measurements to be 2·645.

The presence throughout the rock of small inclusions and cavities made it impossible to obtain very accurate and mutually consistent results. The xylol used in the pycnometer is absorbed by the pore-spaces of the chips to an uncertain extent, so that the results obtained for the density are probably slightly above the true values. The value obtained by the second method is certainly too low, since the effect of the small cavities cannot be eliminated. Nevertheless, the above figures, together with the other properties of the hardened chalk, indicate that it is composed essentially of calcite, and consequently that its porosity is of the order of 3 per cent to 0 per cent.

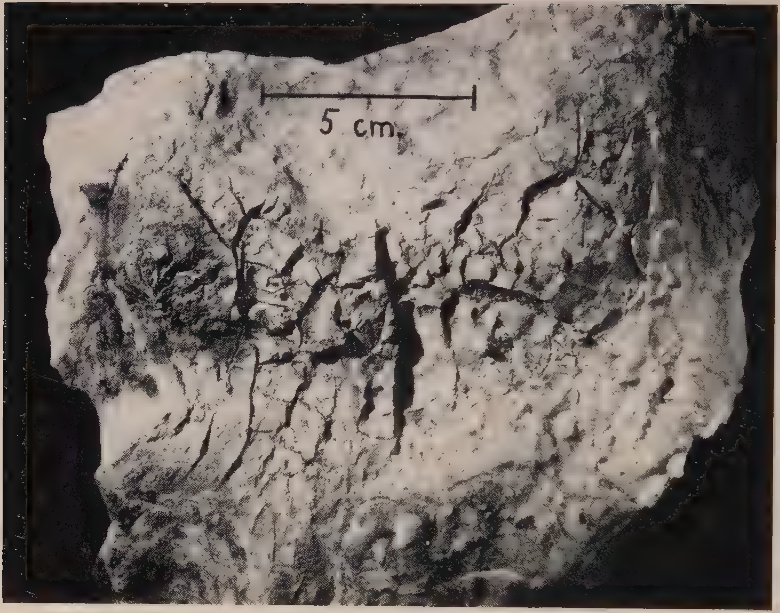
In spite of their marked differences in physical properties, ordinary and hardened chalk are almost indistinguishable in thin section under the microscope. In a slide cut across a boundary between soft and hardened chalk, it is very difficult to see where the boundary occurs, although in hand-specimen the same boundary is immediately obvious to the naked eye. The resemblances include the finely granular appearance of the groundmass, both in ordinary light and between crossed nicols, and in the presence throughout the rock of foraminifera, spheres, *Inoceramus* prisms, and echinoid ossicles. In most of the sections from the tubular stacks, the absence of any increased concentration of the small fossils and shell-prisms indicates that the original groundmass of the chalk has undergone almost no compaction.

Now the density of ordinary chalk from the Sheringham cliff-section is approximately 1·7 ; its porosity is therefore about 40 per cent (assuming it to be composed of calcite, density 2·71). If, therefore, the hardening of the chalk of the tubular stacks had taken place solely by compaction and recrystallisation of the original groundmass, the amount of compaction to be expected would nearly correspond to the original porosity. If the hardened chalk had in fact undergone compaction to 60 per cent of its former volume, it could not escape notice in a thin section containing both soft and hardened chalk. The hardening of the chalk must therefore be due to cementing of the original groundmass with secondary cryptocrystalline calcite.

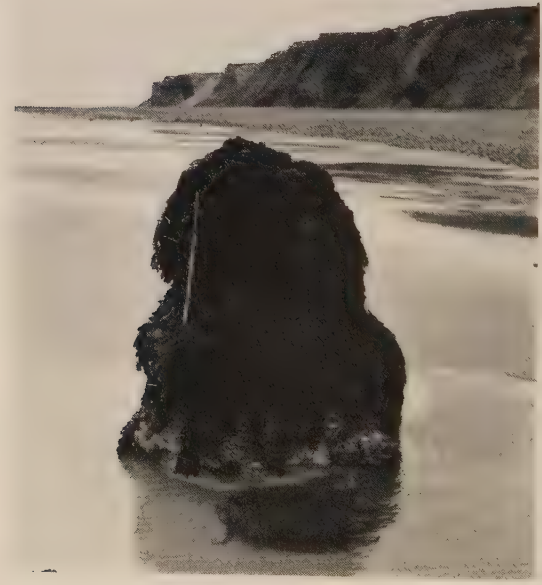
It may be asked why, if the groundmass is cemented with calcite, the cement should be invisible in thin section. This is because the groundmass of ordinary chalk consists mainly of particles less than ten microns in diameter. These particles cannot be individually resolved by the microscope in a rock-slice thirty microns or more thick. The infilling of the minute spaces between the particles with secondary crystals of calcite of the same order of size cannot alter the appearance of the rock in thin section, since the mean refractive index of calcite is nearly the same as that of Canada balsam.

THE CHALK–WEYBOURNE CRAG UNCONFORMITY

At several localities between Weybourne and West Runton, the surface of the Chalk beneath the Weybourne Crag possesses a hardened crust, usually about 2 cm. thick. This similarly proves to be lithified chalk, cemented with cryptocrystalline calcite. It was described in the Geological Survey memoir (Reid and Woodward, 1882, p. 3) as an irregular metamorphism of Pliocene date, similar in texture to the Chalk of Antrim. A similar occurrence of hardened chalk beneath the Norwich Crag has also been reported (Woodward, 1881, p. 75). No suggestion was made as to the cause of the hardening, and the inference that the hardened crust was of



A.—Lithified crust of chalk.



B.—Tubular stack on the foreshore between Sheringham and West Runton.

Weybourne Crag age was apparently based upon the view that the Chalk underwent submarine erosion everywhere beneath the Crag sea.

The following evidence, however, shows that the hardened chalk crust is older than the Weybourne Crag. At West Runton, on the foreshore below the old rifle-range, an outlier of Weybourne Crag resting on the Chalk was found to consist of a breccia of fragments of hardened chalk with a ferruginous sandy matrix. Angular fragments of hardened chalk were also found in the basal flint-bed of the Weybourne Crag in the cliff-section near Weybourne. Pebbles of ordinary chalk also occur in the basal flint-bed, and individual fragments often consist partly of soft and partly of hardened chalk, showing that they were produced by the breaking-up of part of the hardened chalk crust at the time of the Weybourne Crag marine incursion.

DESICCATION-CRACKS IN THE HARDENED CHALK CRUST

The surface of the hardened chalk crust near the Sheringham tubular stacks is covered with a remarkable pattern of desiccation-cracks. When the section is not obscured by debris from the cliff, the desiccation-cracks can be seen to extend almost continuously from the tubular stacks to a point about 200 yards eastwards, covering the surface of a narrow ledge at the base of the cliff. The hardened surface crust is continued downwards into solution-pipes near the cliff-base. These represent " tubular stacks " which have not yet been carved out by the sea, and it is clear that originally all the tubular stacks were similarly in connection with the hardened surface crust. The desiccation-cracks in the hardened chalk crust continue without interruption right up to the mouths of the solution-pipes, but at the point where the horizontal crust turns over into the vertical wall of the pipe, the desiccation-cracks are replaced by the roughened surface which is typical of the internal cavities of the tubular stacks. We may reasonably infer therefore that the hardening of the surface crust and the walls of the solution-pipes took place at about the same time, and under similar conditions. If this conclusion is correct, it follows that the tubular stacks are of pre-Weybourne Crag age.

The dessication-cracks are in many cases perfectly preserved, with sharp, clear-cut edges. They must have been formed by the drying-up of a milky layer of chalk mud (Plate 12, A).

THE PETROGRAPHY OF THE HARDENED CHALK CRUST

Although hardened chalk from the surface crust is similar in appearance and texture to that from the tubular stacks, the microscopic structure of thin sections is somewhat different. The

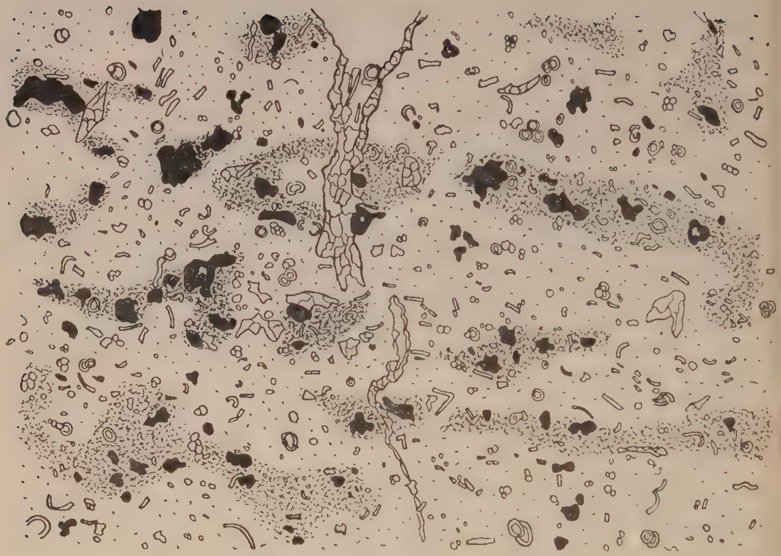


FIG. 3.—Microprojector drawing of a thin section of the lithified surface crust of the Chalk, showing a desiccation-crack in vertical section. Transmitted light, with a deep blue filter.

The whole of the section lies within the lithified crust, the upper surface of which is a short distance above the top of the drawing. The desiccation-crack opens out at the top of the drawing, and in the centre it has undergone slight lateral displacement, the result of uneven shrinkage of the chalk mud. It is filled with crystalline calcite and adventitious debris. The black patches are small particles of limonite ; the heavily stippled areas are light brown streaks of limonite which are almost invisible if a deep blue filter is not used. The groundmass is precisely similar in appearance to ordinary chalk in thin section, except that there is a tendency for the foraminifera and *Inoceramus* prisms to lie horizontally. It will also be noticed that the limonite bands are directly cut across by the desiccation-crack, and are therefore a feature of the original surface layer of chalky mud. The longest dimension of the drawing is 3·4 mm. in the original section.

groundmass is again indistinguishable from that of ordinary chalk, but the foraminifera and *Inoceramus* prisms show a definite tendency to lie horizontally. This is seen in Fig. 3, which shows a vertical section of the surface crust cut across by one of the smaller desiccation-cracks. (The horizontal arrangement of the small fossils is even more pronounced in several other sections.) It is clear from this, that in the case of the surface crust, appreciable compaction of the groundmass *has* taken place.

Traces of limonite are widely disseminated throughout the groundmass of the surface crust, occurring as small brown or black clots and blebs, and as horizontal streaks of a very faint brown colour which are sometimes impossible to see or photograph unless an intense blue filter is used. The desiccation-cracks can be seen to cut sharply across the bands of limonite. The latter must therefore have formed before the cracks, for otherwise some of the bands of limonite would probably turn aside on nearing a crack and run parallel to it for a short distance.

The lateral displacement of the desiccation-crack in the centre of Fig. 3 is particularly noteworthy. It is evidently due to the uneven shrinkage of the chalk mud during drying, for there is no trace of any fracture along the line where the rupture must have occurred. That it happened while the chalk mud was still in a gelatinous condition is further shown by the forked structure at the lower end of the truncated crack, where splitting was temporarily resumed until the chalk mud finally dried up.

The surface crust with desiccation-cracks is usually separated from the overlying ferruginous flint-bed by a thin parting of clay. In places where the ferruginous flint-bed is directly in contact with the hardened chalk crust, desiccation-cracks are absent. A section cut across the boundary between the chalk crust and the ferruginous conglomerate shows that quartz sand-grains are enclosed within the hardened chalk. The hardened chalk contains very little limonite at this point, in spite of the heavy concentration of iron-pan in the conglomerate immediately above it. Moreover, there are no fragments of iron-pan associated with the sand-grains embedded in the hardened chalk. Tests indicate that the porosity of the hardened chalk is here practically zero.

Two conclusions may be drawn from these facts. First, the sand-grains became mixed with a layer of chalk mud before the latter dried up and became hardened. Secondly, the iron-pan in the overlying flint-bed is of later date, and was unable to diffuse into the hardened chalk on account of the very low porosity of the latter.

Inclusions of soft uncemented chalk, in the form of irregular streaks and bands, occur within the hardened chalk crust. They appear to be parts of the original chalk mud which have escaped cementation.

We have now shown that there are four distinct kinds of chalk associated with the tubular stacks :

(a) Ordinary chalk.
(b) Cemented ordinary chalk.
(c) Cemented chalk mud.
(d) Dried chalk mud, uncemented.

One thing still remains to be explained—the cause of the secondary cementation. It must be emphasised that, while it is possible to produce desiccation-cracks in the laboratory by allowing a suspension of chalk in water to evaporate in a dish, the resulting material is no harder than ordinary chalk.

THE ORIGIN OF THE SECONDARY CEMENT

In seeking to account for the hardening of the chalk, the main points to be borne in mind are the following :

1. The surface crust is not, and probably never was, a single continuous sheet covering the whole of the Chalk in this area. Both the tubular stacks and the chalk crust seem to have been local features of the pre-Weybourne Crag land surface.

2. The surface crust is rarely more than 2 cm. thick. Although the walls of a tubular stack are usually much thicker, they are full of small irregular empty cavities. In the underlying basal block (p. 228 above) the cement has hardened the chalk to a depth of only two or three millimetres on either side of individual fissures. In no case has the secondary cement penetrated deeply into solid chalk.

3. The secondary cementation seems to have taken place rapidly (i.e. in a few days or hours, not years or months). The dessication-cracks are very well preserved, their edges sharp and clear-cut, so that it is difficult to understand how they could long withstand normal weathering in an unlithified condition. The cryptocrystalline state of the secondary cement itself suggests that it was formed rapidly.

There are several possible ways in which an indurated crust can form at the surface of a porous rock. For example, in arid climates, evaporation-crusts are frequently formed at the surfaces of permeable limestones by the upward eluviation of groundwater containing dissolved lime salts (e.g. Rogers and du Toit, 1909, pp. 398, 403). There are two principal objections to a similar explanation of the Sheringham surface crust. First, no appreciable evaporation of groundwater could have taken place within the narrow confines of the joints at the bases of the tubular stacks, and consequently the concentration of cement here is unexplained. Secondly, analyses of present-day Chalk groundwater show that calcium bicarbonate is present only to the extent of a few parts per 10,000. This quantity appears to be quite insufficient when it is remembered that the density of the hardened chalk has been increased from about 1·7 to 2·72. The quantity of water to be evaporated would thus have had to be several thousand times the volume of the hardened chalk. It is unlikely that this could have been accomplished within the short space of time that the evidence indicates.

Beaches with cemented surface crusts have frequently been described (Hills, 1949 ; Rogers and du Toit, 1909, p. 398 ; Julien, 1879, p. 343). Opinions differ as to the way in which the crusts are formed : most authorities attribute them to upward eluviation or similar processes involving chemical reactions with sea water. Hills, however, considers that they are formed within the solid rock before the beach platform is cut back, by precipitation from downward-percolating rainwater.

It is clear that neither of these theories can be applied to the

Sheringham chalk crust. The first of them meets with difficulties similar to those encountered in considering evaporation-crusts, and the second is incompatible with the existence of desiccation-cracks in the hardened crust.

A COMPARISON WITH RHIZOCONCRETIONS

A more promising suggestion was made to me by Dr. M. Black. Under certain conditions, calcareous tubular concretions are formed around tree-roots. E. M. Kindle has described examples from the Pleistocene deposits of Canada (Kindle, 1923). A rootlet growing in a loose calcareous sand is capable of precipitating calcareous cement within a radius of several centimetres. The resulting rhizocretion [*sic*] may then weather out as a rod of hard sandstone from the surrounding soft matrix. Rhizoconcretions are usually found enclosing dead and decayed roots. It was accordingly suggested that the humic acids formed during the decay of the root are responsible for the accumulation of calcareous cement. However, in a later paper (Kindle, 1925), rhizoconcretions are described which were found to enclose living roots. These are attributed to the chemical activity of fungi living in association with the affected roots. G. Frenguelli also describes rhizoconcretions surrounding living roots (Frenguelli, 1925), but he considers that Kindle was unjustified in dismissing the earlier hypothesis of humic acids, since living roots are frequently surrounded by decaying woody material. The problem of rhizoconcretions evidently requires further investigation before it can be regarded as solved. Its particular significance in connection with the Sheringham tubular stacks lies in the established fact that localised concentrations of calcareous cement can be formed organically within quite a short time.

It is unlikely that the tubular stacks themselves represent individual rhizoconcretions : a single root could hardly bore a hole a foot in diameter into chalk, and if it could, the hole would not resemble a solution-pipe. On the other hand, it seems quite possible that organic acids were in fact responsible for the cementing of the chalk crust and the walls of the tubular stacks. The localised concentration of the secondary cement and its cryptocrystalline state are closely paralleled in rhizoconcretions formed in several different types of calcareous rocks. They also correspond in the very low porosity of the cemented rock surrounding the root, and the sharp boundary between it and the surrounding porous rock.

The term " humic acid " covers a group of compounds about which comparatively little appears to be known. They are unstable substances, easily decomposed by oxidation (Julien, 1879, p. 330). For our present purposes, however, their precise chemical properties are probably of no particular significance, as it is probable that a wide variety of organic acids are capable of producing almost identical geological effects (Scott, 1922).

I therefore suggest that organic acids, generated within the chalk mud by the decomposition of traces of dead vegetable matter, were the cause of the cementing of the surface crust and the walls of the solution-pipes. The generation of organic acids would automatically cease as soon as the chalk mud dried up completely, and the cementing of the chalk cannot therefore have taken a longer time to accomplish than the process of desiccation. This is in accordance with our previous conclusions (p. 236 above).

The streaks of uncemented chalk occurring within the surface crust (p. 235) probably represent parts of the original chalk mud which were relatively free from decaying vegetable matter. They indicate, moreover, that the chalk mud was initially formed in water that was not appreciably acid, and that the cementation is due to acids that were formed within the chalk mud itself.

The uncompacted cemented chalk of the tubular stacks represents original (i.e. un-puddled) chalk into which " calcium humates " have diffused. The thin plates of hardened chalk associated with the joints in the basal blocks (p. 228) were formed in this manner. Probably decaying plant matter was washed down into the pipes, and the " calcium humates ", formed by solution of chalk at the bottom of the pipes, percolated along the joints and diffused into the adjacent chalk. In several specimens of the desiccated surface crust, the boundary between the hardened chalk mud and the underlying ordinary chalk is characterised by a band of uncompacted cemented chalk, about 2 mm. thick, differing slightly in texture from the cemented chalk mud. This can similarly be explained by the downward diffusion of organic calcium salts from the layer of chalk mud.

It will be as well to end this section with the warning that, until present-day examples can be found of chalk undergoing cementation in this manner, the above conclusions cannot be regarded as more than a working hypothesis.

A NOTE ON THE FLINT IMPLEMENTS OF THE WEYBOURNE CRAG

In view of the inferred pre-Weybourne Crag age of the chalk surface crust (p. 233), it may be worth recording that Dr. Paterson, who has recently drawn attention to the presence of flint-knapping sites at the base of the Weybourne Crag (Paterson, 1948), informs me that he has found a fractured flint embedded in the lithified crust of the Chalk. This observation has been repeatedly confirmed in the course of my own field-work. The flints, whether they are human artefacts or otherwise, were therefore flaked *before* the deposition of the Weybourne Crag, and not, as certain authorities have suggested, by pressure of compaction at some later date.

THE GEOLOGICAL HISTORY OF THE TUBULAR STACKS

The main events in the geological history of the tubular stacks may be summarised as follows :

1. The Chalk uplifted to form land, with a water-table about ten feet below the surface.
2. Formation of solution-pipes.
3. Water containing dead vegetable matter flowed over the surface of the Chalk and into the solution-pipes.
4. Formation of layer of chalk mud.
5. Drying of chalk mud and formation of desiccation-cracks ; hardening of surface crust and walls of solution-pipes.
6. Incursion of Weybourne Crag sea. Entry of marine fauna, and formation of iron-pan in the basal conglomerate.
7. Deposition of Cromer Forest Bed and succeeding deposits.
8. Uplift above sea-level to form present-day land surface.
9. Dissection of tubular stacks by present-day coastal erosion.

It will be noticed that the evidence for the relative dating of the various events rests, in part, upon the assumption that each event occurred at one definite time, and was not later repeated. If later evidence should prove this assumption to be false, some of the conclusions will of course require to be modified.

CONCLUSIONS : THE PRE-WEYBOURNE CRAG LAND SURFACE

It is clear that the Weybourne Crag sea did not everywhere cut a cliff, as the North Sea does now at Weybourne. If it had, the structures described in this paper would not have been preserved. The tubular stacks completely dispose of Osborne Fisher's arguments (quoted on p. 228 above). The incursion must have taken place suddenly, over a land surface already practically at sea-level, after the manner of the recent floods in the neighbourhood of Cley and Salthouse.

On the other hand, the pre-Crag land surface seems to have had a certain amount of low relief, for the fragments of hardened chalk in the basal conglomerate, and the burrows of boring molluscs in the Chalk below the Weybourne Crag, prove that the sea did locally cut into the Chalk. The evidence for the former existence of a water-table at a depth of as little as ten feet below the surface of the Chalk suggests that the relief of the land surface was not very great.

In Chalk country at the present day there are many streams which flow only during the winter, or during rainy weather when the water-table is temporarily raised. Similar conditions may formerly have prevailed in the area under discussion. The layer of desiccated chalk mud could quite easily have formed on the bed of a temporary stream. As was mentioned on p. 227 above, there is some evidence in the cliff-section of shallow stream channels in the surface of the Chalk.

Whatever the exact circumstances may have been, it is at least clear that at the time when the surface crust and the walls of the solution-pipes were hardened, the surface of the Chalk was locally bare of soil, and that water had been flowing over the surface of the Chalk and into the solution-pipes. The cause of the secondary cementation is less certain, but the evidence points to the effects of organic acids, generated within the chalk mud.

The greater part of the pre-Weybourne Crag land surface of Norfolk was probably covered with a layer of terra rossa of the clay-with-flints type. Residual deposits of this kind, derived from the weathering of limestones, usually contain appreciable quantities of iron compounds. The iron-pan at the base of the Crag was probably derived from this source (compare the Melbourne shore platforms described by Hills, 1949, p. 147). In a district of low relief, the soil would probably be peaty, and the streams would be highly charged with small particles of plant debris.

The basal conglomerate of the Weybourne Crag probably represents the remains of the pre-Crag clay-with-flints, thoroughly mixed with sand brought in by the Weybourne Crag sea. The same appears to be true of the material filling the tubular stacks, for these were probably empty when the first incursion of the sea took place.

REFERENCES

Day, A. E. 1928. Pipes in the Coast Sandstone of Syria. *Geol. Mag.*, 65, pp. 412–15.

Fisher, O. 1868. On the Denudations of Norfolk. *Geol. Mag.*, ser. 1, vol. 5, pp. 544–48.

Frenguelli, G. 1925. Sulle Concrezione Calcaree intorno alle Radici di Vegetali Viventi. *Boll. Soc. Geol. Ital.*, 45, pp. 87–90.

Greenly, E. 1900. On Sandstone Pipes in the Carboniferous Limestone at Dwlban Point, East Anglesey. *Geol. Mag.*, n.s. dec. 4, vol. 7, pp. 20–24.

Hills, E. S. 1949. Shore Platforms. *Geol. Mag.*, 86, pp. 137–52.

Julien, A. A. 1879. On the Geological Action of the Humus Acids, *Proc. Amer. Ass. Adv. Sci.*, 28th meeting, pp. 311–410.

Kindle, E. M. 1923. Range and Distribution of Certain Types of Canadian Pleistocene Concretions. *Bull. Geol. Soc. Amer.*, 34, pp. 609–48.

———. 1925. A Note on Rhizocretions. *Journ. Geol.*, 33, pp. 744–46.

Paterson, T. T. 1948. Earliest Known Prehistoric Industry. *Nature*, 161, p. 278.

Prestwich, J. 1855. On the Origin of the Sand and Gravel Pipes in the Chalk of the London Tertiary District. *Quart. Journ. Geol. Soc.*, 11, pp. 64–84.

Reid, C. 1877. On the Succession and Classification of the Beds between the Chalk and the Lower Boulder Clay in the Neighbourhood of Cromer, *Geol. Mag.*, dec. 2, vol. 4, pp. 300–5.

———. 1890. The Pliocene Deposits of Britain. *Mem. Geol. Surv.*

——— and H. B. Woodward. 1882. The Geology of the Country around Cromer. *Ibid.*

Rogers, A. W. and A. L. Du Toit. 1909. *An Introduction to the Geology of Cape Colony. 2nd ed.*, Longmans.

Scott, A. 1922. The Application of Colloid Chemistry to Mineralogy and Petrology. *4th Brit. Ass. Rep. on Colloid Chemistry*, pp. 204–43.

Woodward, H. B. 1881. The Geology of the Country around Norwich. *Mem. Geol. Surv.*

FOOTNOTE

Since writing the above, two further points of interest have been brought to my notice. Mr. E. R. Martin, of Leighton Buzzard, to whom I wrote at the suggestion of Mr. R. V. Melville, informs me that in October 1949 he examined structures in the Chalk of the Sussex coast near Seaford, which were pointed out to him by Mr. R. H. Rowe, an engineer then engaged in rebuilding the Seaford Esplanade. It is clear from the description, photographs and rock-specimens supplied to me by Mr. Martin that the Sussex pipes are essentially similar to the Sheringham tubular stacks. The pipes themselves are much larger, being at least 40 feet in depth (the height of the Chalk in the cliff), and about 4 feet internal diameter, but the hardened walls are usually less than one foot in thickness. The stumps exposed on the beach stand about 2–3 feet high, the upper portions having been broken away by the sea. The age of the pipes, and of the secondary hardening, is not yet known. Mr. Martin considered that the cavities were probably solution pipes, but had no explanation to offer for the cause of the secondary hardening.

Mr. C. W. Wright has informed me of a present-day example of Chalk undergoing secondary cementation in contact with decaying vegetable matter. He has observed that in certain places near Flamborough Head, the Chalk immediately beneath banks of dead seaweed, decaying beneath a cover of shingle, has developed a hardened crust which lithologically resembles specimens of hardened chalk from the Sheringham locality.

The present author hopes to visit these new localities himself to search for additional evidence : in the meantime, it is very satisfactory to have confirmation of the theory of lithification by organic acids, and to learn that the Sheringham tubular stacks are not merely a local curiosity.

EXPLANATION OF PLATES

PLATE 11

A.—The main group of tubular stacks, on the beach about three-quarters of a mile west of Sheringham, August 1947. The stacks, and the Chalk upon which they are based, are unusually well exposed ; normally the beach pebbles are banked up around them. The tide is not quite at full ebb : the former water-table in the Chalk was probably a little above this level. See also Fig. 2.

B.—One of the tubular stacks of the main group. The scale is given by the hammer and two-foot rule.

PLATE 12

A.—A piece of the lithified surface crust of the Chalk, showing desiccation-cracks. The specimen shown was obtained from the base of the cliff beneath the Weybourne Crag, near the main group of tubular stacks. The lighting is from the top left-hand corner. The 5 cm. line gives the scale.

B.—A solitary tubular stack on the foreshore between Sheringham and West Runton, March 1950. The scale is given by the two-foot rule. The stack is submerged except at low tide, hence the covering of seaweed. The sand covering the Chalk is about 1–2 feet thick. The Chalk–Crag unconformity in the cliff-section is concealed by at least 2 feet of beach sand.

NEW AND ENLARGED JURASSIC SECTIONS IN THE COTSWOLDS

By P. J. CHANNON, O.B.E.

[*Received* 8*th December*, 1949]

SUMMARY.—The present paper places on record certain of the more important sections in the Cotswolds, details of which have not been previously published, or which have been greatly extended since earlier publications on them.

As most of these sections are in danger of disappearing through being "worked out", they are now recorded, together with the faunas they have yielded, in some detail; the sections exhibit strata ranging from the Lower Lias up to the Great Oolite.

DURING twenty-five years' residence in or near the Cotswolds the writer has kept numerous exposures in the Jurassic rocks of this region under constant observation and has made extensive collections of fossils, keeping a record of the exact bed from which each specimen was obtained. Many of the sections described in the older works on this classic area are now overgrown or filled in. Other sections, however, have been opened or much extended, even since the appearance of the last two Memoirs of the Geological Survey dealing with parts of the area (L. Richardson and others, 1929, 1933*). As some of these are rapidly changing and in some cases will soon be worked out, it is thought desirable that they and the fossils they have yielded should be placed on record. Most of the sections here described were visited during the Association's Easter Field Meeting in 1949.

Acknowledgment is gratefully made for the determination of numerous specimens by the following :—Drs. K. P. Oakley (porifera) ; L. R. Cox (lamellibranchiata and gasteropoda) ; H. Dighton Thomas (actinozoa) ; H. M. Muir-Wood (brachiopoda) ; L. F. Spath (ammonites)—all of the British Museum ; Prof. H. L. Hawkins of Reading University (echinodermata) ; and Dr. Stanley Smith of Bristol University (belemnites, actinozoa, etc.).

The writer, who has gone abroad, and the editor of the *Proceedings*, are much indebted to Dr. L. R. Cox, F.R.S., for undertaking author's proof corrections.

QUARRIES AT COOPER'S HILL, BROCKWORTH, NEAR GLOUCESTER

The Fiddler's Elbow Quarries, at the sharp bends of that name on the Cheltenham–Painswick road at Cooper's Hill (National Grid Ref. 31/887142), have been observed continuously since 1925, during which time they have been in constant working. They were visited in 1925 by the Cotteswold Field Club, and in the report of this visit (D. E. Finlay, 1925, pp. 80–1) it is recorded that quarries I and II

---

* For list of References, see p. 260.

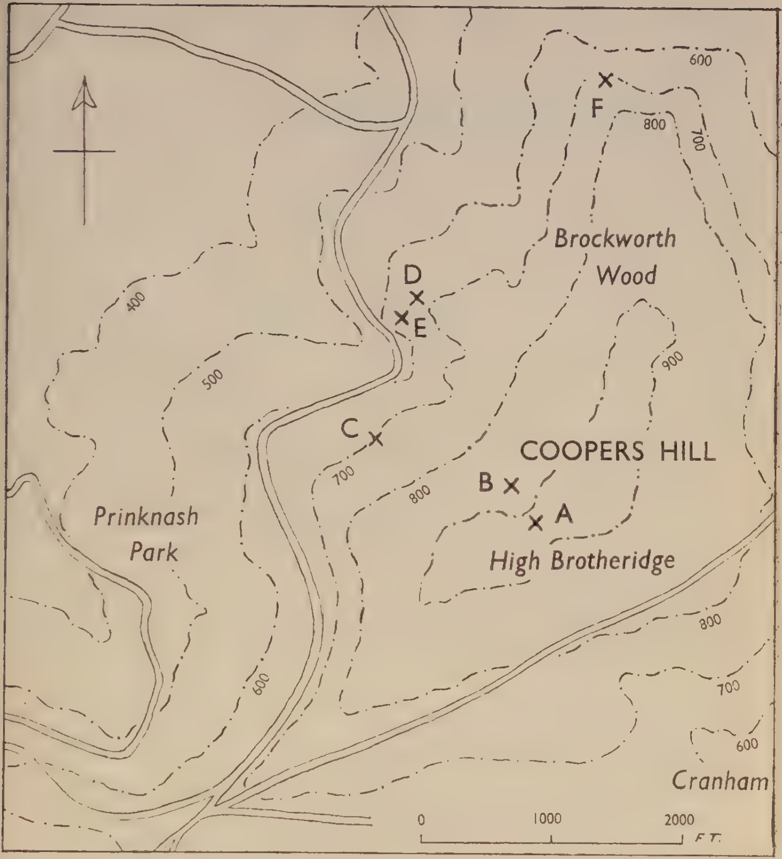


FIG. 1.—Sketch-map of Cooper's Hill; the crosses mark the positions of the sections mentioned. A. High Brotheridge (old quarry in Stonesfield Slate). B. Gun Site Hut Foundations (Lower Fuller's Earth). C. Spring (stiff clay exposed). D. Fiddler's Elbow Quarry II (Inferior Oolite, etc.). E. Fiddler's Elbow Quarry I (Inferior Oolite). F. Section behind Cooper's Hill House (Cotswold Sands and base of Inferior Oolite).

were then both open. The lower quarry (I) was being worked and exhibited much disturbed and slipped Lower Freestone, the top of the Pea Grit with occasional corals, and some Oolite Marl. The top quarry (II) was not then being worked, but showed Clypeus Grit, 14 feet; Upper Trigonia Grit, 8 feet; and Gryphite Grit, 4 feet. It is clear that neither quarry was then cut far into the hill, nor was either nearly as deep as at present. The recorded thickness of the

Clypeus and Upper Trigonia Grits is interesting, as the sole representative of these at present is some 2 feet of mixed rubble ; the thicknesses then seen are in accord with those now found in other parts of Cooper's Hill.

At present the limestone is finely ground, in Quarry I, and used for "liming" agricultural land in the clay area of the valley. The strata are much disturbed and exhibit excellent examples of "cambering" and "gulling". Their proximity to the crest of the Birdlip anticline renders them of particular interest. In Quarry I is to be seen by far the best section of the Fourth (Pea Grit) Coral Bed at present available.

The section behind Cooper's Hill House has been mentioned by Richardson (1904, pp. 9, 63, 69, and 70). From his remarks it would appear that there is some doubt as to whether the Belemnite Bed at the base of the Scissum Beds is a remanié of the Cotswold Cephalopod Bed ; the present writer is of the opinion that it does represent the latter.

Old quarry at summit, High Brotheridge. (Not visited during Field Meeting, 1949)

Stonesfield Slate

			ft.	in.
27.	Hard buff or grey, compact, fine grained limestone, flaggy, with *Placunopsis socialis* Mor. and Lyc. and *Ostrea* sp. ...	Seen	6	0

Gap of from 30 to 40 feet without any exposure.

Gun Site hut foundations. (Not visited)

Fuller's Earth (? *Lower*)

26.	Yellowish stony and clayey marl, very fossiliferous ...	Seen	4	0

Gap of from 40 to 50 feet without any exposure.

At Spring. (Not visited)

25.	Stiff bluish and greenish clay, with thin bed of hard limestone full of *Ostrea acuminata*		?	

Gap of some 125 feet without any exposure.

Fiddler's Elbow, Quarry II. (National Grid Ref. 42/886142)

(?) *Upper Estuarine Clay*

24.	Greenish slate-coloured shaly clay ; barren ...	Maximum	5	0

(?) *Chipping Norton Limestone equivalent*

23.	Massive, hard, white, finely oolitic limestone ; some comminuted shell, no recognisable fossils, but old quarrymen say some very large ammonites (which cannot now be traced) were found when this was being worked...		35	0

Clypeus Grit, First Coral Bed, and Upper Trigonia Grit

22.	The two "grits" are represented by a rubble of both, mixed and stained red with iron, with usual fossils of both ...	Maximum	2	0

Farther round the hill there is a section showing 2 feet 6 inches of Clypeus Grit resting on 4 feet 3 inches of Upper Trigonia Grit. In one place the First Coral Bed is present, with corals, as a slipped mass.

Non-sequence. *Sauzei* and *Witchellia* sub-zones absent

Gryphite and Buckmani Grits. (Not separable)

21.	Hard grey splintery stone, top bored and planed, with large adherent oysters, many fossils		1	0

		ft.	in.
20.	Yellow sandy parting		6
19.	Stone as at 21	1	0
18.	Darker yellow sandy parting	1	0
17.	Stone as at 21	1	0
16.	Yellowish brown and brown sandy parting	1	6
15.	Hard grey splintery limestone, pinkish in places, fossils	1	1
14.	Brown sandy parting, with *Lobothyris buckmani* (Davidson) common	0	4
13.	Hard grey rubbly stone mixed with brown sand	2	0
	Lower Trigonia Grit with Second Coral Bed		
12.	Greyish and brownish rubbly marl, ironshot in places; sometimes lower portion forms a light grey marly band packed with casts of lamellibranchs. Corals frequent	1	6
11.	Brown clayey parting, missing in places	0	4
10.	Very hard greyish and brownish sandy stone. Where the 4-inch parting (above) is present the top is planed, deeply bored, and covered with oysters and *Atreta sollasi*. Full of fossils	5	0
9.	Sandy parting	0	1
8.	Very hard greyish and brownish sandy stone; fossils	2	0
	Non-sequence. *Concava* and upper *Bradfordensis* sub-zones, i.e. Upper Freestone and part of Oolite Marl with Third Coral Bed, absent		
	Oolite Marl		
7.	Compact, whitish, very finely oolitic limestone ... About	4	0
	Lower Freestone		
6.	Yellowish-white, very coarsely oolitic limestone, much broken up and disturbed ... About of which the greater portion forms the top of Quarry I	35	0

Fiddler's Elbow, Quarry I

		ft.	in.
	Fourth Coral Bed		
5.	Hard grey splintery coral limestone with earthy and clayey brown inclusions in which "nests" of brachiopods occur. Corals abundant	11	0
	Pea Grit Series		
4.	A series of much disturbed white, grey, and brown oolitic and pisolitic limestones, with brown sandy partings; in places rubbly and mixed with sand, in others massive. Fossils ... Seen	23	0
	The "Lower Limestone" here merges into the higher beds of the Pea Grit Series and cannot be separated.		

Section "Behind Cooper's Hill House". (National Grid Ref. 42/891148)

		ft.	in.
	Lower Limestone		
	Massive beds, see above.		
	Scissum Beds		
3.	Hard brown ironstained sandstone, top bored	12	2
	Cotswold Cephalopod Bed remanié		
2.	Under surface of Bed (3) consists of a layer crowded with belemnites, with a few unidentifiable ammonites	0	2
	Cotswold Sands		
1.	Yellowish brown earthy and rubbly sand ... Seen	3	0
	Below are brownish and blue Lias clays holding up water—numerous springs.		

Fossils collected from the various beds are as follows:

26. *Fuller's Earth*

Gasteropoda. *Nerinella* sp.

Lamellibranchiata. *Anisocardia fullonica* Cox, *Chlamys* (*Radolopecten*) *vagans* (J. de C. Sow.), *Cucullaea* sp., *Homomya gibbosa* (J. Sow.), *Limatula gibbosa* (J. Sow.), *Limopsis minima* (J. de C. Sow.), *Lopha costata* (J. de C. Sow.), *Meleagrinella echinata* (W. Smith), abundant, *Modiolus buckmani* Rollier, *Osteomya dilata* (Phillips), *Ostrea* (*Liostrea*) *acuminata* J. Sowerby, abundant, *Ostrea* (*Liostrea*) *hebridica* Forbes, *Pholadomya deltoidea* (J. Sow.), *Pholadomya lirata* (J. Sow.), *Placunopsis socialis* Mor. and Lyc., *Pleuromya* sp. (probably *P. uniformis* (J. Sow.)), *Trigonia detrita* (?) Terquem and Jourdy.

Brachiopoda. *Kallirhynchia* cf. *expansa* S. S. Buckman, *Kallirhynchia egfordensis* Muir-Wood, *Kallirhynchia superba* Buckman and vars., *Tubithyris* sp., *Wattonithyris* sp. nov. (form found in Lower Fuller's Earth of Cotswolds).

Echinodermata. Spines of (?) *Acrosalenia* sp.

Actinozoa. *Chomatoseris* [" *Anabacia* "] *orbulites* (Lamouroux) common.

22. *Clypeus Grit*

Cephalopoda. *Parkinsonia* sp. (? *P. subplanulata* Wetzel).

Lamellibranchiata. *Ceratomya striata* (J. Sow.), *Gresslya abducta* (Phillips), *Limatula gibbosa* (J. Sow.), *Lucina* sp., *Chlamys* (*Radulopecten*) cf. *vagans* (J. de C. Sow.), *Pholadomya ovalis* (J. Sow.), *Pleuromya calceiformis* (Phillips), *Pleuromya subelongata* (d'Orb.), *Pleuromya uniformis* (J. Sow.), *Protocardia* sp.

Brachiopoda. *Rhactorhynchia* sp. (2 species) not yet determined, *Stiphrothyris* aff. *birdlipensis* (Dav.), *Stiphrothyris cheltensis* (S. S. Buckman), *Stiphrothyris cotteswoldensis* (S. S. Buckman), *Stiphrothyris* spp.

Echinodermata. *Clypeus ploti* Leske, *Clypeus* sp., *Holectypus depressus* (Leske), *Nucleolites clunicularis* (Fleming).

22. *Upper Trigonia Grit*

Gasteropoda. *Natica* sp.

Lamellibranchiata. *Arcomya tumida* (Mor. and Lyc.), *Chlamys* (*Aequipecten*) *symmetrica* (Mor.), *Gresslya abducta* (Phillips), *Variamussium pumilum* (Lam.).

Brachiopoda. *Acanthothyris spinosa* (Linné), *Kallirhynchia acutaplicata* (Brown), *Kallirhynchia distendens* (S. S. Buckman), *Rugitela hughesi* (Dav.), *Stiphrothyris* sp.

Echinodermata. *Diplopodia pentagona* (M'Coy).

21–13. *Buckmani Grit*

Cephalopoda. Fragments of 3 large Sonninids.

Lamellibranchiata. *Ceromyopsis* sp., *Chlamys dewalquei* (Oppel), *Gryphaea sublobata* Deshayes, abundant, *Isocyprina* cf. *cheltensis* Cox, *Lima* (*Plagiostoma*) *alticosta* Chap. and Dew., *Lima* (*Plagiostoma*) *educta* Whidb., *Lima* (*Plagiostoma*) *schimperi* Branco, *Lucina bellona* d'Orb., *Modiolus imbricatus* J. Sow., very large, *Modiolus* (*Inoperna*) *plicatus* J. Sow., *Pholadomya ovalis* (J. Sow.), *Variamussium pumilum* (Lam.).

Brachiopoda. *Acanthothyris globosa* S. S. Buckman, *Charltonithyris uptoni* (S. S. Buckman), *Lobothyris buckmani* (Dav.) common, " *Terebratula* " *crickleyensis* (S. S. Buckman).

12–8. *Lower Trigonia Grit*

Cephalopoda. *Belemnites* (*Pachyteuthis*) cf. *insculptus* Phillips, *Darellia* sp. juv., *Hyperlioceras liodiscites* (S. Buckman), *Ludwigella* sp. juv., *Nautilus* sp. juv., fragments of large Sonninid.

Gasteropoda. *Ampullospira adducta* (Phillips), *Pictavia* cf. *bajocensis* (d'Orb.), *Ampullospira* cf. *hulliana* (Lyc.), *Neridomus costulata* (Desl.), *Pleurotomaria* sp., *Pseudomelania bicarinata* Wright.

Lamellibranchiata. *Astarte elegans* J. Sow., *Astarte* (*Coelastarte*) *excavata* J. Sow., *Atreta* (*Dimyopsis*) *sollasi* (Whidb.), *Arcomya oblonga* (S. Buckman), *Camptonectes laminatus* (J. Sow.), *Chlamys ambigua* (Münst.), *Chlamys* (*Aequipecten*) *barbata* (J. Sow.), *Chlamys* (*Camptochlamys*) *obscura* (J. Sow.), *Chlamys textoria* (Schloth.), *Cucullaea oblonga* J. Sow., *Cucullaea reticulata* Young and Bird, *Ceratomya bajociana* (d'Orb.), *Ctenostreon pectiniforme* (Schloth.), *Entolium corneolum* (Young and Bird), *Gervillella praelonga* (Lyc.), *Gervillella whidbornei* (Paris), *Goniomya v-scripta* (J. Sow.), *Gresslya abducta* (Phillips), *Gryphaea* cf. *calceoliformis* Schäfle, *Gryphaea sublobata* Deshayes, *Homomya gibbosa* (J. Sow.), *Platymya* cf. *scarburgensis* (Mor. and Lyc.), *Inoceramus obliquus* (Mor. and Lyc.), *Isocyprina* cf. *crossi* Cox, *Isocyprina lucyi* (Witchell), *Isognomon isogmomonoides* (Stahl), *Isognomon oolithicus* (Rollier), *Lima* (*Plagiostoma*) *alticosta* Chap. and Dew., *Pseudolimea duplicata* (J. de C. Sow.), *Lima* (*Plagiostoma*) *schimperi* Branco, *Lima* (*Plagiostoma*) *semicircularis* Goldfuss, *Lopha* cf. *costata* (J. de C. Sow.), *Lopha marshii* (J. Sow.), *Lucina bellona* d'Orb., *Lucina despecta* (Phillips), *Lucina* cf. *oolithica* (Rollier), *Mactromya depressa* (Phillips), *Modiolus cuneatus* J. Sow., *Modiolus imbricatus* J. Sow., *Modiolus* (*Inoperna*) *plicatus* J. Sow., *Mytilus* (*Falcimytilus*) *tumidus* Mor. and Lyc., *Opis cordiformis* Lyc., *Osteomya dilata* (Phillips), *Ostrea* (*Liostrea*) cf. *acuminata* J. Sow., *Ostrea* (*Liostrea*) cf. *sandalina* Goldf., *Ostrea* (*Catinula*) cf. *bradfordensis* Cox, *Oxytoma inequivalvis* (J. Sow.), *Panopea brockworthensis* Cox, Holotype (Brit. Mus. Reg. No. L.76388), *Parallelodon hirsonensis* (d'Arch.), *Pholadomya dewalquei* (Lyc.), *Pholadomya fidicula* J. Sow., *Pholadomya lirata* (J. Sow.), *Pholadomya ovalis* (J. Sow.), *Pinna* (*Stegoconcha*) *ampla* J. Sow., *Pinna buchi* Koch and Dunker, *Placunopsis jurensis* Mor. and Lyc., *Pleuromya calceiformis* (Phillips), *Pleuromya subelongata* (d'Orb.), *Pleuromya subsidens* (Whidb.), *Pleuromya uniformis* (J. Sow.), *Pronoella beneckei* Rollier, *Protocardia buckmani* (Mor. and Lyc.), *Protocardia stricklandi* (Mor. and Lyc.), *Pseudisocardia cordata* (Buckman), *Pseudotrapezium cordiforme* (Desl.), *Quenstedtia rodborensis* (Lyc.), *Tancredia axiniformis* (Phillips), *Tancredia donaciformis* Lyc., *Trigonia costata* J. Sow., *Trigonia signata* Agass., *Trigonia striata* J. Sow., *Trigonia tenuicosta* Lyc., *Eopecten abjectus* (Phillips).

Brachiopoda. *Acanthothyris* sp., *Aulocothyris meriani* (Oppel).

Crustacea. A species not yet determined.

Annelida. *Serpula* cf. *convoluta* Goldf., *Serpula* cf. *grandis* Goldf., *Serpula* cf. *plicatilis* Goldf., *Serpula socialis* Goldf.

Echinodermata. *Acrosalenia* cf. *spinosa* Agass., *Hyboclypeus* cf. *ovalis* Wright, *Paracidaris bouchardi* (Wright).

Polyzoa. *Berenicea archiaci* (?) Haime, *Ceriopora arborescens* Waagen, *Spiropora caespitosa* Lamouroux.

Actinozoa. *Montlivaltia trochoides* Ed. and Haime, *Thamnasteria defranciana* (Michelin), *Thamnasteria terquemi* (Ed. and Haime), *Thecosmilia gregaria* (M'Coy), *Thecosmilia wrighti* Duncan.

7. *Oolite Marl*

Cephalopoda. *Brasilia* sp.

Gasteropoda. "*Natica*" sp.

Lamellibranchiata. *Ceratomya bajociana* (d'Orb.), *Isognomon* sp., *Lucina bellona* d'Orb., *Pleuromya uniformis* (J. Sow.).

Brachiopoda. *Plectothyris fimbria* (J. Sow.), *Pseudoglossothyris leckhamptonensis* (Rollier).

6. *Lower Freestone*

Gasteropoda. *Exelissa* cf. *weldonis* Hudl., *Nerinea* sp.

Lamellibranchiata. *Lima* (*Plagiostoma*) cf. *semicircularis* Goldf., *Lima* (*Plagiostoma*) (?) *schimperi* Branco.

Brachiopoda. *Plectothyris subfimbria* (S. S. Buckman).

Echinodermata. *Clypeus ploti* Leske.

5–4. *Fourth Coral Bed and Pea Grit Series*

Cephalopoda. *Belemnites* (*Pachyteuthis*) *ellipticus* Miller, *Belemnites* (*Pachyteuthis*) cf. *gingensis* Oppel, *Ludwigia laciniosa* (S. Buckman), *Ludwigia* aff. *obtusiformis* (S. Buckman), *Nautilus* sp.

Gasteropoda. (?) *Amberleya ornata* (J. Sow.), *Ataphrus* cf. *labadyei* (d’Arch.), *Amberleya rectiplanata* (Tawney), *Ampullospira canaliculata* (Mor. and Lyc.), *Neridomus pseudo-costata* d’Orb., *Pleurotomaria* cf. *fasciata* J. Sow., *Pleurotomaria* cf. *subplatyspira* d’Orb., *Pseudomelania* sp., *Ptygmatis* sp.

Lamellibranchiata. *Astarte* (*Coelastarte*) *excavata* J. Sow., *Atreta* (*Dimyopsis*) *sollasi* (Whidb.), *Brachidontes* (*Arcomytilus*) sp., *Camptonectes laminatus* (J. Sow.), *Chlamys dewalquei* (Oppel), *Ctenostreon pectiniforme* (Schloth.), *Cucullaea ornata* Buckman, *Entolium corneolum* (Young and Bird), *Gervillella whidbornei* Paris, *Goniomya intersectans* (Smith), *Grammatodon* nov. sp., *Gresslya abducta* (Phillips), *Gryphaea* cf. *calceoliformis* Schäfle, *Inoceramus obliquus* Mor. and Lyc., *Isoarca striata* (Buckman), *Isocyprina* cf. *dustonensis* Cox, *Lima* (*Plagiostoma*) *channoni* Cox, *Lima* (*Plagiostoma*) *crickleyensis* Cox, *Pseudolimea duplicata* (J. de C. Sow.), *Pseudolimea interstincta* (Phillips), *Lima* (*Regalilima*) *oolitica* Lyc., *Lima* (*Plagiostoma*) (?) *placida* Whidb., *Lima* (*Plagiostoma*) *richardsoni* Cox, *Lima* (*Plagiostoma*) *schimperi* Branco, *Lima* (*Plagiostoma*) *tenuistriata* Münst., *Lopha costata* (J. de C. Sow.), *Lucina bellona* d’Orb., *Lucina despecta* Phillips, *Modiolus* (*Inoperna*) *plicatus* J. Sow., *Osteomya dilata* (Phillips), *Ostrea* (*Catinula*) *crickleyensis* Cox, *Ostrea eduliformis* (Schloth.), *Oxytoma inequivalvis* (J. Sow.), *Oxytoma* sp., intermediate between *O. inequivalvis* (J. Sow.) and *O. costata* (Smith), *Parallelodon elongatus* (J. de C. Sow.), *Parallelodon hirsonensis* (d’Arch.), *Pholadomya fidicula* J. de C. Sow., *Pleuromya* (?) *compressiuscula* (Lyc.), *Pleuromya uniformis* (J. Sow.), *Pronoella* sp., *Pseudotrapezium cordiforme* (Desh.), *Pteria complicata* (Buckman), *Tancredia donaciformis* Lyc., *Trigonia costata* J. Sow., *Trigonia formosa* Lyc., *Trigonia producta* Lyc., *Variamussium pumilum* (Lam.), *Eopecten abjectus* (Phillips).

Brachiopoda. *Aulacothyris alveata* (Quenst.), *Costirhynchia shiptonensis* (S. S. Buckman), *Curtirhynchia oolitica* (Dav.), "*Epithyris*" *submaxillata* (Morris), *Granulirhynchia granulata* (Upton) and varieties, *Lophrothyris lophus* S. S. Buckman, *Plectothyris subfimbria* (S. S. Buckman), *Plectoidothyris plicata* (J. Buckman), *Pseudoglossothyris leckhamptonensis* (Rollier), *Pseudoglossothyris simplex* (J. Buckman), *Rhynchonelloidea subangulata* (Dav.) and varieties, *Stroudithyris pisolithica* (S. S. Buckman), *Stroudithyris randwickensis* (Richardson and Upton).

Crustacea. Not yet determined.

Annelida. *Serpula* cf. *substriata* Münst.

Echinodermata. *Acrosalenia spinosa* (Agass.), *Cidaris bouchardi* Wright, *Clypeus* (?) *michelini* Wright, *Clypeus ploti* Leske, *Galeropygus agariciformis* (Forbes), ossicles of *Pentacrinus* sp., *Pygaster ornatus* (Buckman) and varieties, *Pygaster* aff. *conoideus* Wright, *Stomechinus intermedius* Agass., *Trochotiara depressa* (Agass.).

Polyzoa. *Berenicea verrucosa* (Edwards), *Ceriopora arborescens* Waagen, *Ceriopora globosa* Mich.

Actinozoa. *Cladophyllia* sp. near *C. babeana* (d’Orb.), *Comoseris oolitica* (Tomes), *Dimorphoseris* sp. (= *Kobya* sp.), *Isastrea limitata* (Lamouroux), *Isastrea* sp., *Latomeandra flemingi* Ed. and Haime, *Montlivaltia lens* Ed. and Haime, *Montlivaltia painswicki* Duncan, *Thamnasteria defranciana* (Mich.), *Thamnasteria terquemi* (Ed. and Haime), *Thamnasteria walcotti* (Duncan), *Thamnasteria* sp., *Thecosmilia gregaria* (M'Coy), *Thecosmilia rugosa* (Tomes).

Porifera. *Blastinia costata* (Goldf.), *Melonella ovata* Sollas, *Peronidella* cf. *tenuis* (Hinde).

QUARRY AT SNOWSHILL HILL

The quarry is at National Grid Ref. 42/132325, on the east side of the lane from the top of Stanway Hill to Bourton on the Hill, 275 yards south of Small Thorns Farm and two and three-quarter miles west by slightly south of Bourton on the Hill.

This is probably the section mentioned by L. Richardson (Richardson and others, 1929, p. 89) as being "260 yards SW. x W. of Bourton Hill Farm," and as then showing only Chipping Norton Limestone. It has been worked continuously for many years, and is now much further back into the hill, consequently revealing higher strata. At present, so far as is known, it is the only section in the county exhibiting Sharps Hill Beds.

In the following, correlations with the beds at Sharps Hill are suggested at (5), (4), and (3) ; *vide* W. J. Arkell (1947, page 63). There is no trace of the bed with gastropods which have been referred to the freshwater genus *Viviparus*, such as is found in Oxfordshire.

	Stonesfield Slate	ft.	in.
7.	Hard, brown and cream coloured, fissile, oolitic limestone and rubble ; *Ostrea*	4	0
	Sharp's Hill Beds (? Lower)		
6.	Light yellow marly sand with oysters	0	6
5.	(?) Upper Nerinea Bed. Slightly darker yellow, marly and stony sand ; abundant lamellibranchs and gasteropods, and some crushed brachiopods	1	6
4.	(?) Coral Bed. Darker brown or blackish marl, clayey in places, packed with corals mainly of three species, some up to 12 inch in diameter, with numerous oysters, beds of "beef", and much "race". In one place a large mussel bed of *Modiolus imbricatus* J. Sow.	1	6
3.	(?) Lower Nerinea Bed. Light greyish oolitic, soft marly limestone and sand, full of lamellibranchs, and *Nerinea* and other gasteropods	0	6
	Chipping Norton Limestone		
2.	Massive rather soft sandy stone ; orange, yellow, and cream coloured. Harder at base, and full of lamellibranch casts. At the base is a large lenticle of tough black clay, barren, and extending for about a third of the length of the face, dying out at each end and with a maximum thickness of one foot	6	0
	(?) Hook Norton Beds		
1.	Several beds of very hard, massive, sandy stone, reddish, yellow, and cream coloured. Few traces of fossils but full of black vegetable specks. Incipiently nodular, exactly as at Newpark		

	ft.	in.
Quarry, Longborough. Oysters and *Lima cardiiformis* J. Sow. occur. No trace of " Signata Bed " at top... Maximum seen	30	0
Floor of quarry similar.		

The following fossils have been collected from the Sharp's Hill Beds :—

Pisces. *Hybodus* sp. Teeth, species not yet determined.

Cephalopoda. Belemnites, species not yet determined.

Gasteropoda. *Amberleya bathonica* Cox and Arkell, *Angaria* n. sp., *Aphanoptyxis eulimoides* (Lyc.), *Ataphrus* n. sp., *Chartroniella* n. sp., *Cylindrites acutus* (J. de C. Sow.), *Dicroloma lorieri* (d'Orb.), *Dicroloma pupaeforme* (d'Arch.), *Natica* sp., *Neridomus cooksoni* (Desl.), *Neridomus pseudocostata* (d'Orb.), *Pleurotomaria* sp., *Pseudomelania* (*Oonia*) *conica* (Mor. and Lyc.).

Lamellibranchiata. *Anisocardia rostrata* (J. Sow.), *Bakevellia waltoni* (Lyc.), *Corbula buckmani* Lyc., *Corbula hulliana* (Mor.), *Costigervillia crassicosta* (Mor. and Lyc.) (L. R. Cox coll.), *Cuspidaria bathonica* Cox and Arkell (L. R. Cox coll.), *Eocallista antiopa* (Thev.), *Lopha gregaria* (J. Sow.), *Modiolus imbricatus* J. Sow., *Modiolus* (*Inoperna*) *plicatus* J. Sow., *Modiolus* (*Falcimytilus*) *sublaevis* J. de C. Sow., *Nucula* (*Palaeonucula*) *waltoni* Mor. and Lyc., *Nuculana* (*Dacryomya*) *lacryma* (J. de C. Sow.) abundant, *Ostrea* (*Liostrea*) *hebridica* Forbes, *Pholadomya lirata* J. Sow., *Placunopsis socialis* Mor. and Lyc., *Pleuromya calceiformis* (Phillips), *Pleuromya uniformis* (J. Sow.), *Protocardia lingulata* (Lyc.), *Protocardia lycetti* (Rollier), *Protocardia* cf. *stricklandi* (Mor. and Lyc.), *Tancredia angulata* Lyc., *Tancredia gibbosa* Lyc., *Trigonia pullus* J. de C. Sow.

Brachiopoda. Rhynchonellid and Terebratulid, not yet determined.

Echinodermata. *Clypeus ploti* Leske, *Clypeus* sp., not yet determined.

Actinozoa. *Cyathophora pratti* Ed. and Haime, *Isastrea limitata* (Lamouroux) common, *Microsolena excelsa* Ed. and Haime abundant, *Thamnasteria lyelli* (Ed. and Haime).

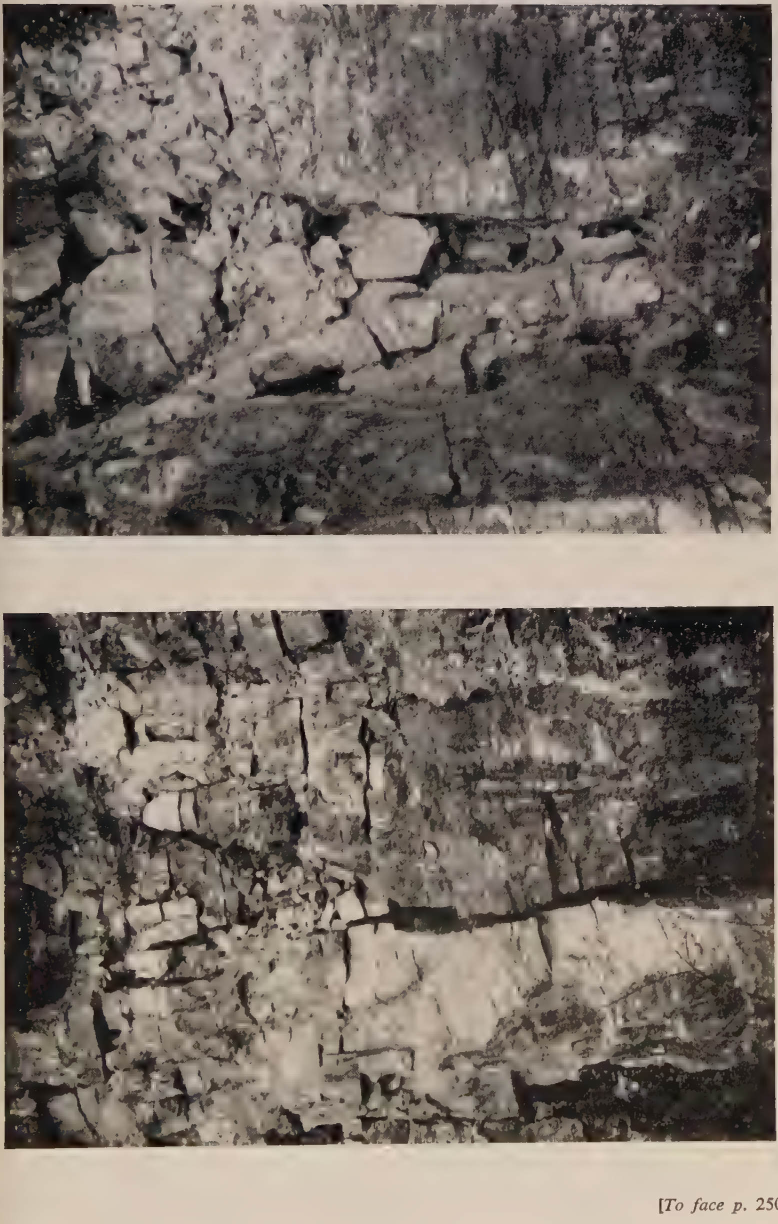
SIMMONDS QUARRY, BURLEIGH

This quarry seems to have escaped description hitherto. It has been worked for many years and is still producing fine cut and carved blocks for building work for bridges and walls, and for interior work, such as fire surrounds. It is near the little Post Office at Burleigh, some two and three-eighth miles south-east by south of Stroud, the village being just to the east of the Stroud–Minchinhampton road, and on the edge of Minchinhampton Common.

The section is of particular interest since for a very long period subsequent to the classic work of Morris and Lycett little, if any, serious collecting was carried out in these beds until the writer started collecting from here in 1939.

Being situated on the top edge of a very deep and steep valley, with massive limestone resting on Fuller's Earth Clay, conditions are ideal for " cambering " ; very fine examples of this are observable and also of successive stages in the formation of V-shaped tensional fissures filled with debris of overlying beds, for which the old quarrying term " gulls " has recently been revived (Hollingworth and others, 1944, p. 11) (Plate 13).

PROC. GEOL. ASSOC., VOL. 61 (1950). PLATE 13.



Successive Stages in the Formation of "Gulls" in the Great Oolite Limestone of Simmonds Quarry, Burleigh, Glos.

[To face p. 250.

For the sake of comparison, H. B. Woodward's section (1894, pp. 278–9) of what is now known as the " Crane Quarry " only some half mile away, and thought to be the classic exposure described by Morris and Lycett, is given by the side of the Burleigh section.

Minchinhampton Beds

CRANE QUARRY (*H. B. Woodward*) National Grid Ref. 31/857015	ft.	in.	SIMMONDS QUARRY, BURLEIGH National Grid Ref. 31/862015	ft.	in.
8. Rubble ... ... 7. " Dry-Wall Stone " ...	6	0	4. Subsoil and rubble, the latter greyish and yellowish, oolitic, and slabby, few fossils	3	6
6. Hard pale smooth limestone	1	0			
5. Wedge-bedded " Planking ". *Purpuroidea* at base...	8	0	3. " Planking " equivalent. A series of massive beds of oolitic limestone of varying texture, white, grey, and yellowish brown, with fossils distributed throughout, the most fossiliferous portion, packed with gasteropods and lamellibranchs, being a stratum from 6 inches to 12 inches thick of very white, softish, shelly limestone nearly at the top of the series. There appears to be no trace of *Purpuroidea* or of the cephalopods, attributed to the " Planking " in Crane Quarry	10	6
4. Parting with *Lima cardiiformis*.—" The Scroff." In the only part of this section now visible this parting is from 18 inches to 24 inches thick. It consists of massive, raggy, very hard, coarsely oolitic brownish limestone with wide stony, marly partings at top and bottom, the marl being crammed with very large *Trigonia pullus*, *Lima cardiiformis*, and *Ostrea hebridica*; it also contains some other lamellibranchs and a few gasteropods and brachiopods, *Epithyris* (immature) and *Kallirhynchia* (immature). From it the writer obtained a large ammonite body chamber, attributed by Dr. W. J. Arkell to (probably) *Procerites* sp.			2. " The Scroff." Yellowish stony marl full of large *Ostrea hebridica*, *Lima cardiiformis*, with a few other fossils...	0	1

CRANE QUARRY
(*H. B. Woodward*)
National Grid Ref. 31/857015

	ft.	in.
3. Soft white stone ...	6	0
2. Current-bedded " Weatherstone " and " Shelly Beds "	15	0
1. Fuller's Earth Clay ...	?	

SIMMONDS QUARRY, BURLEIGH
National Grid Ref. 31/862015

	ft.	in.
1. " Weatherstone." A series of hard, massive, current-bedded, coarsely oolitic limestones, shelly, brownish, or grey, with very thin sandy partings. Excellent building stone ... ... Seen	30	0
Below. Fuller's Earth Clay, invisible, throws out numerous springs.		

The following fossils have been collected from Simmonds Quarry with, in addition, some thirty new species of small gasteropods, which are being described by Dr. L. R. Cox.

Pisces. *Mesodon* sp. Teeth, fish scales.

Gasteropoda. *Acmaea roemeri* (Mor. and Lyc.), *Actaeonina* (*Ovacteonina*) *phasianoides* (Lyc.), *Ampullospira insignis* (Lyc.), *Ampullospira naticiformis* (Piette), *Ampullospira stricklandi* (Mor. and Lyc.), *Ataphrus comma* (Lyc.), *Ataphrus discoideus* (Mor. and Lyc.), *Ataphrus heliciformis* (Mor. and Lyc.), *Ataphrus labadyei* (d'Arch.), *Brachytrema* sp., *Buvignieria duplicata* (J. de C. Sow.), *Ceritella acuta* Mor. and Lyc., *Ceritella actaeoniformis* (Piette), *Ceritella conica* Mor. and Lyc., *Ceritella lycettea* Buv., *Ceritella morrisea* Buv., *Chartroniella bunburii* (Mor. and Lyc.), *Chartroniella infrastriata* Cox and Arkell, *Coelostylina* (*Pseudochrysalis*) *minutissima* (Lyc.), *Cylindrites acutus* J. de C. Sow., *Cylindrites altus* Mor. and Lyc., *Diarthema paradoxum* (Desl.), *Trochotoma obtusa* (Mor. and Lyc.), *Exelissa formosa* (Lyc.), *Lissochilus peroni* (Cossmann), *Mathilda tricarinata* (Mor. and Lyc.), *Melanioptyxis altararis* (Cossmann), *Metriomphalus lyelli* (d'Arch.), *Monocuphus pagoda* (Mor. and Lyc.), *Globularia michelini* d'Arch., *Neridomus cooksoni* (Desl.), *Nerinella scalaris* d'Orb., *Ooliticia exigua* (Lyc.), *Ozodochilus imbricatus* (Mor. and Lyc.), *Ozodochilus subobtusus* (d'Orb.), *Paracerithium gardineri* Cox and Arkell, *Procerithium* (*Cosmocerithium*) *betulae* (d'Orb.), *Procerithium* (*Rhabdocolpus*) *kilverti* Cox and Arkell, *Procerithium minchinhamptonense* Cox and Arkell, *Procerithium* (*Xystrella*) *tancredi* Cox and Arkell, *Procerithium* (*Rhabdocolpus*) *variabile* (Mor. and Lyc.), *Procerithium* (*Rhabdocolpus*) *pulchrum* (Lycett), *Promathildia tennanti* (Mor. and Lyc.), *Pseudomelania communis* (Mor. and Lyc.), *Pseudomelania* (*Oonia*) *leymeriei* (d'Orb.), *Pseudomelania* (*Oonia*) *subglobosa* (Mor. and Lyc.), *Rissoina ancliffensis* Cox and Arkell, *Rothpletzella formosa* (Mor. and Lyc.), *Scurria bathiensis* (Rollier), *Scurriopsis anglica* Haber, *Symmetrocapulus latus* (J. de C. Sow.), *Symmetrocapulus tessoni* (Desl.), *Trochoturbella coniformis* (Piette), *Zebina laevis* (J. de C. Sow.).

Lamellibranchiata. *Anisocardia loweana* (Mor. and Lyc.), *Astarte* (*Coelastarte*) *compressiuscula* Mor. and Lyc., *Astarte* (*Eriphylopsis*) *cotswoldensis* Cox and Arkell, *Astarte oolitharum* Cossmann, *Astarte* (*Ancliffia*) *pumila* J. de C. Sow., *Astarte squamula* d'Arch., *Astarte wiltoni* Mor. and Lyc., *Barbatia prattii* (Mor. and Lyc.), *Brachidontes* (*Arcomytilus*) *bathonicus* (Mor. and Lyc.), *Camptonectes annulatus* (J. de C. Sow.), *Camptonectes laminatus* (J. Sow.), *Camptonectes* (*Camptochlamys*) *retiferus* (Mor. and Lyc.), *Camptonectes rigidus* (J. Sow.), *Camptonectes* (*Camptochlamys*) *rosimon* (Cossm.), *Chlamys* (*Radulopecten*) *vagans* (J. de C. Sow.), *Corbula buckmani* Lyc., *Corbula corinensis* Cox and Arkell, *Eocallista antiopa* (Thev.), *Eomiodon fimbriatus* (Lyc.), *Eomiodon flexicostatus* (Lyc.), *Eonavicula minuta* (J. de C. Sow.), *Exogyra arata* Lissajous, *Gervillella monotis* (Desl.), *Gervillella ovata* (J. de C. Sow.), *Grammatodon* nov. sp., *Isognomon* (*Mytiloperna*) *bathonicus* (Mor. and Lyc.), *Lima* (*Plagiostoma*) *bynei* Cox and Arkell, *Lima* (*Plagiostoma*) *cardiiformis* J. Sow., *Pseudolimea duplicata* (J. de C. Sow.), *Lima* (*Plagiostoma*) *ovalis* J. Sow., *Lima* (*Plagiostoma*) *subcardiiformis* Greppin, *Limopsis minima* (J. de C. Sow.), *Lopha costata* (J. de C. Sow.), *Lopha gregarea* (J. Sow.), *Lucina cardioides* d'Arch., *Mactromya impressa* (Mor. and Lyc.), *Modiolus imbricatus* J. Sow., *Modiolus* (*Inoperna*) *plicatus* J. Sow., *Mytilus* (*Falcimytilus*) *sublaevis* J. de C. Sow., *Musculus lycetti* (Mor.), *Nuculana* (*Dacryomya*) *lacryma* (J. de C. Sow.), *Nucula* (*Palaeonucula*) *variabilis* J. de C. Sow., *Nucula* (*Palaeonucula*) *waltoni* Mor. and Lyc., *Opis* (*Coelopis*) *pulchella* Lyc., *Ostrea* (*Catinula*) *ancliffensis* Cox and Arkell, *Ostrea* (*Liostrea*) *acuminata* J. Sow., *Ostrea* (*Liostrea*) *hebridica* Forbes, *Parallelodon bynei* Cox and Arkell, *Parallelodon rudis* (J. de C. Sow.), *Placunopsis fibrosa* Laube, *Placunopsis socialis* Mor. and Lyc., *Protocardia buckmani* (Mor. and Lyc.), *Protocardia stricklandi* (Mor. and Lyc.), *Pteroperna costatula* (Desl.), *Quenstedtia bathonica* (Mor. and Lyc.), *Sphaeriola oolithica* (Rollier), *Tancredia brevis* Mor. and Lyc., *Tancredia extensa* Lyc., *Tancredia planata* Mor. and Lyc., *Tancredia subcurtansata* Lyc., *Tancredia truncata* Lyc., *Trigonia* (*Vaugonia*) *moretoni* Mor. and Lyc., *Trigonia pullus* J. de C. Sow.

Brachiopoda. *Epithyris* sp., *Kallirhynchia* (?) sp.

Crustacea. *Pagurus* sp.

Annelida. *Serpula* cf. *flagellum* Münst.

Echinodermata. *Acrosalenia* sp., *Cidaris* cf. *bradfordensis* Wright, *Cidaris wrightii* Desor, *Hemicidaris* sp., *Millericrinus* (?) sp., ossicles, *Nucleolites clunicularis* Smith, *Pentacrinus* sp., ossicles.

SLADE QUARRY, SALPERTON

At National Grid Ref. 42/070217, on the south side of the Cheltenham–Stow on the Wold road some nine miles from Cheltenham. This quarry appears to have escaped published description, so far as is known to the writer.

It is very large, being worked mechanically for stone which is crushed in the quarry. It had been in work for a considerable time before the writer first visited it in 1938. Its principal geological interest lies in the blue and brownish clays separating the overlying Taynton Stone from the Stonesfield Slate and therefore occurring at the horizon of the Sevenhampton Beds (i.e. Sevenhampton Rhynchonella Bed, *Ostrea acuminata*/*hebridica* Limestone, and the Sevenhampton Marl).

The writer inclines to the view that these clays represent the Rhynchonella Bed because of the abundance of crushed brachiopods, especially Rhynchonellids, in some portions ; similar crushed brachiopods occur commonly in the district in the Rhynchonella Bed but rarely in the Sevenhampton Marl. Dr. W. J. Arkell, on the other hand (*in litt.*), is of the opinion that the clays represent the Sevenhampton Marl. In the absence of any trace of the *Ostrea* *acuminata/hebridica* Bed in or near the quarry, the question cannot be settled.

The section, in 1948, was as follows :—

		ft.	in.
	Taynton Stone		
9.	Yellow oolitic limestone, weathering flaggy, few traces of fossils	8	3
8.	Similar limestone	4	0
7.	Similar limestone	0	6
6.	Softer brownish oolitic limestone with *Ostrea*, *Meleagrinella echinata* and a few other fossils, in an iron-cemented sandy layer, holes in which are filled with clay	0	5
5.	Somewhat harder, yellow oolitic limestone, with comminuted shell and some small, rolled lamellibranchs	0	9
	(?) *Sevenhampton Rhynchonella Bed*		
4.	Stiff brownish clay, sandy at top and passing downwards into dark blue, shaly clay ; full, in places, of crushed brachiopods, *Chlamys vagans*, *Ostrea* and other shells, and crinoid ossicles, and containing numerous small, very thin, flat, blue-stained pebbles, which are frequently bored and covered with Serpulae ; the pebbles themselves apparently contain no fossils and their origin cannot at present be determined, but they are *not* Ostrea Limestone	4	0
	Non-sequence. *Ostrea acuminata/hebridica* Limestone and Sevenhampton Marl missing		
	Stonesfield Slate		
3.	Massive, hard, grey, blue-hearted stone with sandy partings ; *Trigonia impressa*. Lignite	4	0
2.	Softer, dark brown, sandy stone	1	0
1.	Massive hard grey stone, with *Ostrea* ; *Placunopsis socialis* ; large *Procerites gracilis* ... Seen	9	6
	Floor of quarry, dark brown sandy stone, very strongly ripple marked, and with " Pot-Lids ".		
	Water held up at bottom of quarry.		

This quarry has yielded the following fossils :

1–3. *Stonesfield Slate*

Cephalopoda. *Procerites gracilis* (J. Buckman) (in Sedgwick Museum, Reg. No. J.23017), *Belemnites* (*Belemnopsis*) *bessinus* d'Orb.

Lamellibranchiata. *Camptonectes laminatus* (J. Sow.), *Chlamys* (*Radulopecten*) *vagans* (J. de C. Sow.), *Pseudolimea duplicata* (J. de C. Sow.), *Lima* (*Plagiostoma*) *cardiiformis* J. Sow., *Placunopsis socialis* Mor. and Lyc.

4. *Sevenhampton Beds*

Lamellibranchiata. *Chlamys* (*Radulopecten*) *vagans* (J. de C. Sow.), *Lopha costata* (J. de C. Sow.), *Ostrea* (*Liostrea*) *acuminata* J. Sow., *Ostrea* (*Liostrea*) *hebridica* Forbes, *Placunopsis fibrosa* Laube.

Brachiopoda. *Kallirhynchia* sp., crushed (probably *K. deliciosa* S. S. Buckman).

Echinodermata. Echinoid spines.

5–9. *Taynton Stone*

Lamellibranchiata. *Camptonectes annulatus* (J. de C. Sow.), *Camptonectes* (*Camptochlamys*) *retiferus* (Mor. and Lyc.), *Chlamys* (*Radulopecten*) *vagans* (J. de C. Sow.), *Lima* (*Plagiostoma*) *bynei* Cox and Arkell, *Limopsis minima* (J. de C. Sow.), *Meleagrinella echinata* (W. Smith), *Ostrea* (*Liostrea*) *hebridica* Forbes, *Oxytoma* sp., *Placunopsis socialis* Mor. and Lyc., *Pleuromya* sp., *Protocardia* sp., *Trigonia pullus* J. de C. Sow.

Brachiopoda. *Avonothyris* sp., *Epithyris* (?) sp., *Kallirhynchia* sp.

QUARRY EAST OF HILLSOME (OR ILSOM) FARM, TETBURY

At National Grid Ref. 31/908945. The quarry is on the west side of the lane leading from the Tetbury–Cirencester main road to Long Newton, one and a half miles out of Tetbury, half a mile from the junction of the lane with the main road.

It was visited by the "A.3" excursion of the International Geological Congress in 1948 and a few notes on it, based on observations by Mr. G. A. Kellaway, were published on p. 10 of the Guide to that Excursion. The writer has visited it several times and it has also been examined by Dr. W. J. Arkell, to whom acknowledgment is made for his reading of the section and notes on the strata above the quarry (*in litt.*), which are incorporated in the following :—

		ft.	in
	Forest Marble		
	"Comes in higher up the hill."		
	White Limestone		
	"Brash in stubble field east of the quarry shows this, with more Dagham Stone, continues above Bed 6 (in the quarry) for another 15 to 20 feet."		
6.	In quarry. Typical rubbly and marly white limestone, very fossiliferous, with quantities of a small brachiopod of the *Digonella* type	4	0
5.	White, finely oolitic, rather flaggy limestone, obliquely bedded "Identical with such beds in the Middle Epithyris Bed of Oxon."	14	0
4.	Brownish oolite, "some ropy structure", smooth, oyster-covered top	2	0
3.	Dagham Stone. Hard white limestone, cavernous, top planed and bored, with adherent oysters	2	0
	(Dr. L. R. Cox informs me that a brown marl full of well preserved brachiopods constituting a new fauna fills depressions in the surface of this bed.)		
2.	Fine-grained white oolite	8	0
	(?) *Taynton Stone*		
1.	Coarsely oolitic, shelly, white limestone, false-bedded, weathering flaggy ; many small lamellibranchs ... ... Seen to	4	0

The record of a boring made for the West Gloucestershire Water Co. quite near the quarry is given below and acknowledgment is made to that company for the information given. This shows a total thickness of Great Oolite of 127 feet 3 inches, which includes all the beds shown in the quarry and in the field to the east. The cores from this boring are still to be seen, dumped in a small disused quarry at the side of the main road opposite the lane junction.

Ilsom Bore Hole. (National Grid Ref. 31/908947)

	ft.	in.
Forest Marble	–	–
Great Oolite	127	3
Fuller's Earth	122	4
Clypeus Grit and/or Doulting Stone	24	2
Upper Trigonia Grit	11	6
Lower Freestone	24	0

		ft.	in.
Pea Grit Series		87	6
Scissum Beds		–	–
Cotswold Cephalopod Bed		–	–
Cotswold Sands		198	6
Upper Lias Shale	Seen	13	0
		608	3

Fossils collected from the White Limestone of Bed 6 of the quarry are as follows :—

Gasteropoda. *Ampullospira* cf. *stricklandi* (J. de C. Sow.), *Cylindrites* sp., *Dicroloma* sp., *Globularia* [*Natica*] sp., *Nerinea* sp., *Pleurotomaria* sp.

Lamellibranchiata. *Anisocardia caudata* (Lyc.), *Anisocardia islipensis* (Lyc.), *Anisocardia truncata* (Mor.), *Camptonectes rigidus* (J. Sow.), *Ceratomya concentrica* (J. de C. Sow.), *Ceromyopsis undulata* (Mor. and Lyc.), *Chlamys* (*Radulopecten*) *vagans* (J. de C. Sow.), *Corbis lajoyei* d'Arch., *Lucina bellona* d'Orb., *Pholadomya lirata* (J. Sow.), *Pholadomya* (?) *socialis* Mor. and Lyc., *Pleuromya calceiformis* (Phillips), *Pleuromya uniformis* (J. Sow.), *Protocardia* sp., *Trigonia* cf. *elongata* (J. de C. Sow.).

Brachiopoda. (?) *Digonella* spp. (not yet described), *Epithyris* sp. (not yet described), *Kutchithyris fulva* (S. S. Buckman), *Rhactorhynchia* sp.

STANLEY WOOD QUARRY AND MARMONTSFLAT WOOD QUARRY

Stanley Wood quarry is at National Grid Ref. 31/018803, on the south side of the Stroud–Dursley road, opposite to Stanley Wood (recently cut down). It has been disused for very many years but still affords a good section. It was visited by the " A.3 " Excursion of the International Geological Congress in 1948, by the Geologists' Association in 1934, and previously by several other gatherings of geologists.

In the report of the Geologists' Association Easter Field Meeting (Gardiner and others, 1934, p. 447), it is stated that Upper Trigonia Grit rests on a bored irregular surface of false-bedded Lower Freestone, and that Upper Freestone and Oolite Marl are missing ; the report makes no mention of the overlying Clypeus Grit (or Doulting Stone).

This section is of special interest because of its situation in the area where the Doulting Stone, Rubbly Beds and " Anabacia " Limestones developed further south merge laterally into the Clypeus Grit of the Mid- and North Cotswolds (*vide* W. J. Arkell, 1933, page 236, and diagram, page 197).

In the writer's opinion the top beds here are quite characteristic Doulting Stone, not Clypeus Grit. Further, in his opinion, the Upper Trigonia Grit rests upon Upper, not Lower, Freestone.

The reasons for classifying the top beds as Doulting Stone are that lithologically the rock is typical of the Doulting Stone, and unlike any of the various Cotswold Clypeus Grit facies ; that the fauna is very sparse, unlike that of the Clypeus Grit, the few fossils found being one or two *Stiphrothyris* sp. [=" *Terebratula globata* " auctt.], *Pleuromya uniformis*, *Acanthothyris* sp., and nests of *Variamussium pumilum*, such as are usual in the Doulting Stone.

With regard to the Freestone, an examination of some of the adjacent quarries fails to bear out the suggestions that the Upper Trigonia Grit here rests on Lower Freestone. At the quarry in Marmontsflat Wood (not visited by the Geologists' Association), only 300 yards to the south, evidence is seen for Upper Freestone and Oolite Marl equivalent ; this latter section has therefore been given with the Stanley Wood section. Moreover, many sections in the near neighbourhood show undoubted Upper Freestone—four feet at Scar Hill, Nailsworth ; five feet at Balls Green, Nailsworth ; and very thin representatives at Selsley Hill, Rodborough Hill, and Woodchester.

Stanley Wood Quarry. (National Grid Ref. 31/018803)

Top of quarry approximately 700 feet above O.D.

		ft.	in.
	Subsoil		
	Doulting Stone (*Clypeus Grit Equivalent*)		
4.	Creamy white and greyish, rather hard, finely oolitic limestone, somewhat flaggy, few fossils. *Variamussium pumilum*, " *Terebratula globata* " auctt., *Pleuromya*, all scarce ... About	4	0
	Upper Trigonia Grit		
3.	Typical hard greyish crystalline limestone, massive, shelly, with *Acanthothyris spinosa* and other usual fossils in plenty	6	6
2.	Parting of marly, stony, clay with Upper Trigonia Grit fossils	0	6
	Non-Sequence		
	Upper Freestone		
1.	Massive, creamy-white, hard oolitic limestone, no fossils seen. Top planed, bored, and oyster covered ... ... Seen	4	0

Marmontsflat Wood Quarry. (National Grid Ref. 31/015802)

300 yards to south of above

Top of quarry approximately 650 feet above O.D.

		ft.	in.
	Subsoil	1	0
	Upper Freestone		
4.	Fairly massive white oolitic limestone, with annelid borings and *Globirhynchia tatei* sparingly. *Plectothyris fimbria* not found	4	0
	Oolite Marl Equivalent		
	(No true Oolite Marl is present)		
3.	Conspicuous band of lightish-brown, coarsely oolitic limestone, partly weathered to sand. No fossils seen	1	0
	Lower Freestone		
2.	Massive bedded, whitish and light brown oolitic limestone, rather soft. No fossils seen	12	0
1.	As above, but harder, used for building stone ... ... Seen	15	0

JARVIS NEW QUARRY, NEAR CIRENCESTER

At National Grid Ref. 41/995999. The quarry is on the north side of the Cirencester–Tetbury road a little more than two miles south-west of Cirencester.

This section was recorded by H. B. Woodward (1894, p. 282) ; it has been observed frequently by the writer since 1940, when quarrying operations were greatly extended to provide stone for aerodromes, and is now worked much further back into the hill.

		ft.	in.
	Subsoil		
	Forest Marble		
	Forest Marble facies		
8.	Hard oolitic limestone, whitish, weathering fissile. Few fossils, *Ostrea*	3	0
	Kemble Beds facies		
7.	Hard, shelly, whitish oolitic limestone, with iron staining. Some beds resembling *Ostrea acuminata* Limestone, being very hard, slabby and packed with small oysters. Some Terebratulids. *Chlamys* (*Radulopecten*) *vagans*	10	0
6.	"*Lima cardiiformis* Bed." Softer creamy-white, coarsely oolitic limestone, weathering rubbly. Packed with *Lima* (*Plagiostoma*) *cardiiformis* and brachiopods. Some corals and at one time a bed of *Modiolus imbricatus*	3	0
5.	Massive, dirty white oolitic limestone, no fossils seen	4	0
4.	Soft bed of oolitic and sandy clay packed with very small oysters. Holds up water ... ... From 0 6 to	0	9
3.	Massive, creamy-white softish oolitic limestone, planed, bored, and oyster covered surface at base. No other fossils seen ...	10	0
2.	Similar rock, resting on a strongly ripple-marked surface ...	2	0
1.	Similar rock ... ... Seen to	11	0

The quarry has yielded the following fossils :—

Lamellibranchiata. *Anisocardia* sp., *Camptonectes* (*Camptochlamys*) *obscurus* (J. Sow.), *Lima* (*Plagiostoma*) *cardiiformis* J. Sow., abundant, *Modiolus imbricatus* J. Sow., *Ostrea hebridica* Forbes, abundant.

Brachiopoda. *Burmirhynchia oxoniensis* S. S. Buckman, *Epithyris oxonica* Arkell, abundant, *Epithyris oxonica* var. *alta* Arkell, *Stiphrothyris capillata* Arkell.

Also numerous polyzoa and some corals.

DAGHAM DOWNS QUARRY

At National Grid Ref. 41/999061. The quarry is on east side of Ermin Street (the main Gloucester–Cirencester road), a little beyond the fourteenth milestone from Gloucester.

This section was described by L. Richardson (Richardson and others, 1933, p. 68) ; it then showed a total depth of section of 9 feet 8 inches. After being disused for many years, it was reopened about 1940–1 for quarrying stone for aerodromes, being very extensively worked by mechanical means. This quarrying is still in progress and the section now shows a depth of thirteen feet, as follows :—

		ft.	in.
	Subsoil		
	White Limestone		
3.	White oolitic limestone, weathering rubbly at top	5	0
2.	Hard, white oolitic limestone, "incipient" Dagham Stone. *Epithyris* sp. common, and other fossils	4	0
1.	Dagham Stone. Typical, very hard, white, flinty, cavernous. Level top surface bored, oyster covered, and strongly ripple-marked ... ... Seen to	4	0
		13	0

It has yielded the following fossils :—

Gasteropoda. *Nerinea* sp.

Lamellibranchiata. *Anisocardia truncata* (Mor.), *Ceromyopsis undulata* (Mor. and Lyc.), *Chlamys* (*Radulopecten*) *vagans* (J. de C. Sow.), *Isognomon* sp., *Lima* (*Plagiostoma*) *cardiiformis* J. Sow., *Lopha costata* (J. de C. Sow.), *Pholadomya* (?) *socialis* Mor. and Lyc., *Protocardia buckmani* (Mor. and Lyc.).

Brachiopoda. *Digonella* cf. *digonoides* (S. S. Buckman), *Epithyris* sp. common, *Kutchithyris fulva* (S. S. Buckman).

Echinodermata. *Acrosalenia lycetti* Wright, *Clypeus mülleri* Wright, *Clypeus* sp., echinoid spines.

Actinozoa. A large coral, not yet determined.

WOODCHESTER PARK FARM QUARRY

At National Grid Ref. 31/810011, at Woodchester Park Farm, just north of the lane from Nailsworth to Nympsfield, some half mile north-west by west of the latter village, is a very old but interesting section. It was described by Witchell (1882, p. 74) and has probably been disused for fifty or sixty years, but the section is still accessible, as follows :—

(?) *Upper Fuller's Earth and Minchinhampton Beds Equivalent*

Subsoil

		ft.	in.
6.	Limestone, fairly hard, buff, oolitic, with few fossils, passing gradually down into	4	0
5.	Sandy stone, yellow and reddish-yellow, very hard, almost porcellanous in texture, incipiently nodular, with *Morrisiceras morrisi* (Oppel),[1] *Isognomon* sp., *Nerinea* sp., *Ceratomya* sp., *Nautilus* sp. Passing down into ... ... Average	2	0
4.	Limestone, buff, oolitic, hard, flaggy, with few fossils Average	4	0
3.	Marl parting, sandy or clayey, persisting almost throughout whole face of section	0	1
2.	Limestone, white, porcellanous in texture, very hard, incipiently nodular, few fossils ; passing gradually down into ...	2	6
1.	Limestone, oolitic, buff, flaggy, few fossils ... ... Seen	8	0

NOTE : At Lynch Knoll, near by and a little to the east, an old quarry at the top of the Knoll shows hard, buff, oolitic, flaggy limestone, resting on Fuller's Earth Clay, which is holding up water to form a pond in the centre of the quarry.

The special interest of these two sections lies in the light they throw upon the problems arising when attempting to correlate the Great Oolite and Fuller's Earth of the Cotswolds with beds of similar age farther south.

BLOCKLEY STATION BRICK AND TILE WORKS

The clay pit here, at National Grid Ref. 42/183370, was noticed by L. Richardson (Richardson and others, 1929, p. 15) ; it seems that it was opened in 1925, on a small scale only. The pit is now very large and was regularly in work for a long period up to about

---

[1] Found in 1948, now in Sedgwick Museum, Reg. No. J.20255.

1940–1 ; it was closed during the war and is still disused. Collecting here is unusually good ; the nodules with which the slopes and bottom of the excavation are covered have had time to weather down, strewing the place with fossils.

The exposure is wholly Lower Lias; no detailed investigation of the zones present has been possible, owing to slipping and growth of vegetation on the slopes, but the ammonite evidence shows the presence of the *davoei* and *ibex* zones. The pit is thirty to forty feet deep ; it has yielded the following fossils :—

Cephalopoda. *Androgynoceras* or *Beaniceras* sp. (trans. from *A. maculatum* to *B.*), *Beaniceras* cf. *luridum* (Simpson), *Liparoceras cheltiense* (Murchison), *Lytoceras fimbriatum* (J. Sow.), *Nautilus striatus* (J. Sow.), *Belemnites* (*Passaloteuthis*) *auricipitis* (Lang), *Belemnites* (*Hastites*) cf. *clavatus* Blainville, *Belemnites* (*Hastites*) cf. *microstylus* Phillips, *Belemnites* (*Megateuthis*) cf. *paxillosus* Phillips.

Gasteropoda. *Amberleya subimbricata* (d'Orb.), *Pleurotomaria similis* (J. Sow.), *Ptychomphalus expansus* (J. Sow.).

Lamellibranchiata. *Astarte camertonensis* Moore, *Chlamys* (*Aequipecten*) *acuticosta* (Lamarck), *Chlamys* (*Aequipecten*) *prisca* (Schlotheim), *Grammatodon inequivalis* (Goldf.), *Gryphaea regularis* (Desh.), *Hippopodium ponderosum* J. Sow., *Inoceramus* cf. *pinnaeformis* Dunker, *Inoceramus substriatus* Münst., *Lima* (*Antiquilima*) *succincta* (Schlotheim), *Liostrea* sp., *Mactromya cardioides* (Phillips), *Modiolus hillanus* J. Sow., *Modiolus morrisii* Oppel, *Modiolus scalprum* J. Sow., *Myoconcha decorata* (Münst.), *Oxytoma inequivalvis* (J. Sow.), *Parallelodon buckmani* (Richardson), *Pholadomya ambigua* (J. Sow.), *Pinna folium* Young and Bird, *Placunopsis* sp., *Pleuromya costata* (Young and Bird), *Plicatula spinosa* J. Sow.

Brachiopoda. Rhynchonellid (not yet determined).

Annelida. *Serpula* sp.

Echinodermata. Ossicles of *Pentacrinus* sp.

REFERENCES

ARKELL, W. J. 1933. *The Jurassic System in Great Britain.*

———. 1947. *The Geology of Oxford.*

COX, L. R., KELLAWAY, G. A. and F. B. A. WELCH. 1948. Guide to Excursion A.3—" William Smith " Excursion (Environs of Bath). *International Geological Congress, XVIII Session.*

FINLAY, D. E. 1925. Excursion to Cranham and Cooper's Hill. *Proc. Cotteswold Nat. Field Club*, 22, pp. 79–81.

GARDINER, C. I. and others, 1934. Easter Field Meeting 1934. The Gloucester District. *Proc. Geol. Assoc.*, 45, pp. 445–50.

HOLLINGWORTH, S. E. and others, 1944. Large-scale Superficial Structures in the Northampton Ironstone Field. *Quart. Journ. Geol. Soc.*, 100, pp. 1–44.

RICHARDSON, L. 1904. *A Handbook to the Geology of Cheltenham and Neighbourhood.*

——— and others, 1929. The Country around Moreton-in-Marsh. *Mem. Geol. Surv.*

——— ———. 1933. The Country around Cirencester. *Mem. Geol. Surv.*

WITCHELL, E. 1882. *The Geology of Stroud.*

WOODWARD, H. B. 1894. The Jurassic Rocks of Britain. Vol. IV. The Lower Oolitic Rocks of England (Yorkshire excepted). *Mem. Geol. Surv.*

FIELD MEETING IN THE COTSWOLDS

Easter, 1949, 14th–19th April

Director: P. J. Channon, O.B.E. (*Report by* L. R. Cox)

[*Received 8th December*, 1949]

FIELD meetings based on Cheltenham have been held by the Association on only two previous occasions, in 1874 and 1897. There have, however, been several other meetings in the Cotswold area, based on Cirencester (1887, 1925), Stroud (1908), Evesham (1904) and Gloucester (1934). The present meeting was attended by twenty-two members of the Association. Lt.-Col. A. M. Cockshott, of Cheltenham, very kindly acted as Field Meeting Secretary, and Mr. G. Makins Smith, Secretary of the Cotteswold Naturalists' Field Club, deputised for him on two days when he was unable to be with the party. Weather conditions were ideal.

Thursday, 14th April

At 9 a.m. the party assembled in a room at Cheltenham College kindly placed at their disposal by the Headmaster, Mr. A. G. Elliot-Smith, M.A. Here the Director had arranged, from his own collection, named series of fossils from the various subdivisions of the Cotswold Jurassic sequence which were to be seen by the party in the field. He also gave a short talk on the general programme of the meeting. The display of fossils remained open every night and was found most helpful by those members of the party who wished to identify the specimens they had collected during the day.

Good Friday, 15th April

The party went by coach to the large quarries in the Cotswold escarpment at the Fiddler's Elbow road bend at Cooper's Hill, near Gloucester (Channon, 1950, p. 242*). The Director pointed out that, owing to the situation of this locality on one flank of the Birdlip Anticline, which had suffered intermittent uplift during Inferior Oolite times, there were significant gaps in the succession, some beds seen at Cleeve Hill or elsewhere in the Cotswolds being absent. The upper part of the Oolite Marl and the Upper Freestone were missing, as also (owing to a more important unconformity below the Upper Trigonia Grit) the Notgrove Freestone, Witchellia Grit, and Phillipsiana and Bourguetia Beds.[1] Fossils seen or collected by the party included fragments of two very large ammonites (Sonninids ?) from the Buckmani Grit, several good corals from the Pea Grit Coral Bed, plentiful lamellibranchs from the Lower Trigonia Grit, *Lobothyris buckmani* from the Buckmani Grit, and many brachiopods and other fossils from the Pea, Clypeus, and Upper Trigonia Grits. It was observed that several faults affected the beds in the quarries. Very fine examples of " cambering " in the Inferior Oolite beds were also observed, due to their position above the Lias clays found lower in the escarpment.

---

[1] See G. A. Kellaway and F. B. A. Welch, 1948, Plate xii (section of Cotswold Inferior Oolite Beds, modified from W. J. Arkell).

* For list of References, see p. 267.

The party then inspected the small section behind Cooper's Hill House showing Cotswold Sands overlain by Scissum Beds and Lower Limestone. The ground on the opposite side of the main road to the Fiddler's Elbow quarries was next inspected. A large amount of Lower Lias clay from an excavation in the district had been dumped at this spot and had blocked up the springs issuing from the junction of the Lias and Inferior Oolite. The result had been a considerable landslide.

After lunch the party climbed by coach *via* Birdlip to the top of Crickley Hill, crossing on the way the line of the Birdlip Anticline, where the succession is still less complete than at Cooper's Hill owing to the absence of Lower Trigonia, Buckmani, and Gryphite Grits, in addition to the subdivisions already mentioned. At the very crest of the anticline erosion has cut down to the Upper Freestone (observed in passing), but later beds are seen on either side. The next stop was on the far side of the anticline at Tuffley's Quarry (near the Air Balloon Inn). Here a fuller although still incomplete succession (described by Richardson, 1904*a*, p. 110, Plate ix) was seen of Upper Trigonia, Buckmani, and Lower Trigonia Grits, all very fossiliferous, resting on Upper Freestone. The magnificent view over the Vale of Gloucester, formed of Lower Lias and older rocks, with the outliers of Churchdown and Robins Wood Hills, was particularly noted.

The route was now continued down Crickley Hill, passing on the right the prominent cliffs of Pea Grit. The party descended at Cold Slad and examined the very fossiliferous Pea Grit, the Fourth Coral Bed, and (on top) the Lower Freestone, well seen in several quarries along the escarpment. The numerous fossils collected included *Pygaster* sp., *Trochotiara* sp., *Neridomus pseudocostata*, *Isognomon isognomonoides*, and *Ludwigia* sp. After tea at Birdlip the party returned direct to Cheltenham.

Saturday, 16th April

From Cheltenham the coach took the main Stow-on-the-Wold road, past Andoversford, and the first stop was at the large Slade Quarry, north of Salperton (Channon, 1950, p. 253). The beds exposed consist of Stonesfield Slate and Taynton Stone, separated by about four feet of brownish and blue clay, large dumps of which near the entrance to the quarry provide a good opportunity for collecting the rather crushed brachiopods, oysters, etc., which it contains. The Director pointed out how the section here differs from those formerly seen at Sevenhampton Common, some four miles to the north-west (Woodward, 1894, p. 294; Richardson, 1904*a*, p. 163), where the Sevenhampton Marl, *Ostrea acuminata* Limestone, and Sevenhampton Rhynchonella Bed separate the Stonesfield Slate and Taynton Stone. The heavy ripple-marking on the Stonesfield Slate forming the floor of the quarry was observed, and *Trigonia impressa*, the characteristic fossil of the Slate, and a few other species were collected.

The party now went *via* Fox Hill and Temple Guiting to the Guiting Stone quarries three-quarter mile north-east of that village. The quarries, which are no longer worked, show 25–30 feet of Yellow Guiting Stone (the equivalent of the Pea Grit subdivision of the Inferior Oolite) and 30–40 feet of White Guiting Stone (the equivalent of the Lower Freestone above). They were found to be sparsely fossiliferous in places, yielding a number of small shells and (from the Yellow Stone) a specimen of *Chlamys dewalquei*.

The next stop was at Snowshill Hill quarry, two miles ESE. of Snowshill village and just west of Bourton Hill Farm. Here is a very fine section (Channon, 1950, p. 249) of Chipping Norton Limestone overlain by Sharp's Hill Beds with a capping of Stonesfield Slate. The chief interest of the quarry lies in the excellent collecting from the Sharp's Hill Beds, which are stripped from the top of the limestone. Very fine specimens of the four coral species *Cyathophora pratti*, *Thamnasteria lyelli*, *Microsolena excelsa*, and *Isastrea limitata* were obtained by members of the party, together with numerous small lamellibranchs and gastropods and a tooth of the fish *Hybodus*?

The party now entered Westington Hill quarries, about two miles south of Chipping Campden, which were last visited by the Association in 1904 (Richardson, 1904*b*, p. 395). Here Lower Freestone was formerly mined in galleries which still exist. The stone is used for building work and to make fireplaces, mantels, etc. Examples were inspected by the party and were much admired. The Director gave reasons for referring all the overlying beds to the Oolite Marl except for those at the very top, which are Upper Freestone. The Oolite Marl is very fossiliferous, and members collected many brachiopods (including *Plectothyris fimbria*, *Globirhynchia subobsoleta*, and *Epithyris submaxillata*), and a number of lamellibranchs and gastropods.

The large disused brickpit near Blockley Station (Channon, 1950, p. 259) was next visited. The floor of the pit was strewn with highly fossiliferous weathered nodules from the upper beds of the Lower Lias and formed a prolific collecting site.

After tea at Chipping Campden a short halt was made at a sandpit two-thirds of a mile ENE. of Snowshill, which the Association had visited in 1904 (Richardson, 1904*b*, p. 392). This pit shows a section of Harford Sands, consisting of a massive bed of fossiliferous sandstone two feet thick underlain by fine white quartzose sand and overlain by sandy loam. The Director pointed out that all subdivisions included in the *concavus* subzone, missing at the Birdlip Anticline, were present in this area, but that there were now no good sections showing the Snowshill Clay, the Tilestone, or the Blockley (Naunton) Clay. On the return journey to Cheltenham glimpses were obtained of the well-known Cotswold village of Broadway and of the picturesque Stanway House. At Cleeve Hill the Director pointed out the Phillipsiana and Bourguetia Beds and the Witchellia Grit. This locality, in the deepest part of the Cleeve Hill Syncline, is the only place in the Cotswolds where these formations are developed.

Easter Sunday, 17th April

The party travelled by coach *via* Painswick to Stroud, thence up Rodborough Hill (passing, near the top, old quarries in Upper Trigonia and Clypeus Grits), and across Minchinhampton Common. Here the so-called Crane Quarry was pointed out. This is the last remaining quarry of those which yielded the well-preserved Great Oolite fossils localised as "Minchinhampton", found in museums throughout the world and monographed nearly a century ago by Morris and Lycett. It has been partly filled with rubbish within recent years, and the party noted with satisfaction that a notice prohibiting its further use for this purpose was now displayed. This was the result of representations made in the previous summer by the International Geological Congress. The first stop was at the village of Burleigh, on the edge of the Common, where the Great Oolite beds still worked in Simmonds Quarry (Channon, 1950, p. 250) were examined. The Director pointed out the horizon from which he had obtained a large series of fossils, and several members made collections from slabs of the fossiliferous rock. Particular interest was shown in the superficial structures visible in the quarry face. A spring, probably thrown out by the Fuller's Earth Clay below the oolitic beds, was inspected behind the house adjoining the quarry.

The coach next crossed Minchinhampton Common to the Amberley Inn, on the western side, and here an old quarry was examined showing Clypeus and Upper Trigonia Grits resting on Notgrove Freestone. A descent was now made into the deep valley that carries the Stroud–Nailsworth road, and the road taken leading up to Selsley Common, where most of the pits in which Inferior Oolite Beds were formerly well exposed are now overgrown or filled in. The next stop was at the quarry on the southern side of the road leading to the west along the edge of the Cotswold escarpment, opposite the now completely felled Stanley Wood. This quarry had been visited by the Geologists' Association in 1934, but the Director now suggested a new interpretation of the succession (Channon, 1950, p. 256).

Lunch was taken at the well-known view-point of Frocester Hill. The old quarries showing Freestone overlying Lower Limestone, with the Scissum Beds exposed by the roadside below, were examined. The Cephalopod Bed from which rich collections have been made here in the past and the underlying Cotswold Sands are now grassed over, but several ammonites (including *Grammoceras toarciense*, *Phlyseogrammoceras electum* and *Pseudogrammoceras fallaciosum*) were collected from the talus slope between the present road and the old track.

The next stop was at Woodchester Park Farm quarry (Channon, 1950, p. 259), showing a section of beds regarded as Fuller's Earth Rock, but members of the party were not so successful as the Director had been recently in finding one of the few ammonites (*Morrisiceras*) which these beds of the Great Oolite Series have yielded. Next came a long drive to Tetbury and thence to the large quarry in Great Oolite beds (Channon, 1950, p. 255), opened during the last war near Hillsome Farm, one and a quarter miles north-east of the town. Many fossils were collected, including an interesting brachiopod, resembling the genus *Digonella*, found in the upper part of the succession.

The last section visited during the day was Jarvis' new quarry, near Cirencester (Channon, 1950, p. 257), showing fossiliferous Kemble Beds. Here members collected many specimens of the brachiopod *Epithyris oxonica* and of the lamellibranch *Lima cardiiformis*, together with corals and other fossils. After tea at Cirencester the party returned to Cheltenham direct.

Easter Monday, 18th April.

The party went by coach *via* Leckhampton Hill to Birdlip, and thence along Ermin Street, to Dagham Downs Quarry, near Cirencester (Channon, 1950, p. 258). Here the typical Dagham Stone, with its irregular, ramifying, tubular cavities, was examined, and many brachiopods and a few echinoids, together with a coral, collected. The next stop was at the large Sisters' Quarry, near Baunton (Richardson and others, 1933, p. 65), showing Kemble Beds of Great Oolite facies with White Limestone forming the floor of the quarry. A good specimen of the echinoid *Acrosalenia* was obtained, but otherwise collecting proved disappointing. Thence the party made its way through Cirencester and Fairford to a quarry at Southrop (Richardson and others, 1933, p. 78) showing two feet ten inches of Cornbrash overlying several feet of false-bedded limestone representing the Kemble Beds. The Cornbrash consists of the zone of *Cererithyris intermedia* overlain by the lower part of the zone of *Ornithella obovata*, both highly fossiliferous.

On passing again through Fairford, some members of the party took the opportunity to visit the church with its famous stained-glass windows, and others examined a heap of Cornbrash in the churchyard yielding the characteristic fossils *Meleagrinella echinata* and *Pleuromya uniformis*. The site of the special excavation of the Fairford Coral Bed from which Miss Slatter had obtained a large number of corals described by R. F. Tomes (1883) was then visited. It had been re-discovered by the Director to lie in the middle of a ploughed field about one-third of a mile east of Honeycombe Leaze Farm, and is still marked by a circular depression. The farmer had very kindly ploughed up this part of the field in preparation for the party, with the result that some fifty corals were collected. A small adjacent section was also examined, showing the coral bed, six inches thick, overlain by one foot of Kemble Beds and underlain by eight feet of hard oolitic limestone (White Limestone). A specimen of the coral *Thecosmilia slatteri* was obtained here.

The next stop was at the village of Sunhill, where the large Hampton Fields quarry (Richardson and others, 1933, p. 58), shows about seven feet of White Limestone of variable lithological characters overlain by about six feet of Kemble Beds of Forest Marble facies. The quarry is now nearly worked out. *Modiolus imbricatus* and *Mytilus* (*Falcimytilus*) sp. were collected from the White Limestone. At Meysey Hampton Lane, near Sunhill, a small section in Lower Cornbrash was examined and many fossils characteristic of this horizon were obtained from the ploughed-up surface of the adjoining field ; they included *Kamptokephalites kamptus* and *Clydoniceras* sp. together with various lamellibranchs, brachiopods, and echinoids.

At this spot the President took the opportunity to propose votes of thanks to the Director and Field Meeting Secretaries. He particularly paid tribute to the great amount of preliminary work done by the Director, both in arranging the display of fossils at Cheltenham College and in providing for every member of the party very full typewritten details of every exposure visited, together with a large section of the Fiddler's Elbow quarries. Tea was again taken at Cirencester, and on the return journey to Cheltenham a short halt was made to inspect Seven Springs, one of the sources of the Thames.

Tuesday, 19th April

From Cheltenham the party drove direct to Eyford Hill, four miles west of Stow-on-the-Wold, and visited the old Cotswold [Stonesfield] Slate pits (Richardson and others, 1929, p. 115), where many mammalian and other remains have been obtained in the past. The pits have not been worked since about 1940, but the spoil-heaps were found still to provide material for the collector, and members of the party were successful in obtaining a number of teeth of *Hybodus*, *Strophodus*, and *Teleosaurus*, together with specimens of *Belemnopsis fusiformis*. Stacks of slates still being weathered and others in which the process was completed were observed.

The next stop was at Newpark Quarry, Longborough (Richardson and others, 1929, p. 89), where about twenty feet of Chipping Norton Limestone are separated by a thin, impersistent seam of clay or sandy marl from a nodular limestone referable to the Hook Norton Beds (uppermost Inferior Oolite), forming the floor of the quarry. The Director stated that the top few feet of the Hook Norton Beds had yielded an important series of reptilian remains. The late Mr. C. I. Gardiner, Curator of the Stroud Museum, had obtained the first specimens of these and they had been described by the late Professor S. H. Reynolds (1939). Subsequently, the Director himself had collected further important specimens, now in the British Museum (Natural History) ; among them were major portions of the cranium, together with vertebrae and scuta, of *Steneosaurus*, and portions of the upper and lower jaws and several other bones of *Megalosaurus*. His discovery of the ammonite *Parkinsonia* cf. *neuffensis* in the same bed clearly established their age. The quarry had not been worked since about 1940.

The party now drove, *via* Stow-on-the-Wold, Andoversford, and Seven Springs, to Leckhampton Hill, on the outskirts of Cheltenham, and lunch was taken in a quarry near the Sanatorium, showing the junction of Pea Grit and Lower Freestone. Afterwards the classic Leckhampton quarries were visited, now showing Pea Grit, Lower Freestone, Oolite Marl, Upper Freestone (with a somewhat rare fossiliferous bed), and Gryphite, Lower Trigonia, and Buckmani Grits. A walk to the top of the hill led next to the site of the Iron Age Camp which had been excavated in 1925. Notes on this camp, kindly contributed by Mrs. E. M. Clifford, had been distributed by the Director to the party. After inspecting the camp the members visited an extensive quarry in very fossiliferous Upper Trigonia Grit, and showing also Gryphite Grit and Notgrove Freestone. This concluded the programme of the Field Meeting.

REFERENCES

CHANNON, P. J. 1950. New and Enlarged Jurassic Sections in the Cotswolds. *Proc. Geol. Assoc.*, 61, pp. 240–60.

KELLAWAY, G. A. and F. B. A. WELCH. 1948. Bristol and Gloucester District, 2nd ed. *Geol. Surv., British Regional Geology.*

REYNOLDS, S. H. 1939. On a Collection of Reptilian Bones from the Oolite of Stow-on-the-Wold, Gloucestershire. *Geol. Mag.*, 76, pp. 193–214.

RICHARDSON, L. 1904*a*. *Handbook to the Geology of Cheltenham.*

————. 1904*b*. Excursion to the Vale of Evesham and the North Cotteswolds. *Proc. Geol. Assoc.*, 18, pp. 391–408.

———— and others. 1929. The Country around Moreton-in-Marsh (Explanation of Sheet 217). *Mem. Geol. Surv.*

———— ————. 1933. The Country around Cirencester (Explanation of Sheet 235). *Mem. Geol. Surv.*

TOMES, R. F. 1883. On the Fossil Madreporaria of the Great Oolite of the Counties of Gloucester and Oxford. *Quart. Journ. Geol. Soc.*, 39, pp. 168–96.

WOODWARD, H. B. 1894. The Jurassic Rocks of Britain. IV. The Lower Oolitic Rocks of England (Yorkshire Excepted). *Mem. Geol. Surv.*

THE JUNCTION OF THE GAULT AND LOWER GREENSAND IN EAST SUSSEX AND AT FOLKESTONE, KENT[1]

(*Weald Research Committee Report No. 42*)

By R. CASEY, F.G.S.

[*Received* 21*st December*, 1949]
[*Read* 14*th April*, 1950]

CONTENTS

PAGE
INTRODUCTION 269
STRATIGRAPHICAL AND FAUNAL SUCCESSION
(a) Folkestone 269
(b) East Sussex 276
CORRELATION AND INTERPRETATION OF THE SECTIONS
(a) General Comparison 282
(b) Stratigraphical Relations of the Gault and Lower Greensand in East Sussex 284
PHOSPHATIC NODULE-BEDS AND THE PALAEONTOLOGICAL RECORD ... 286
PALAEONTOLOGICAL NOTES ON THE AMMONITES 289
REFERENCES 295
DISCUSSION 297

SUMMARY.—Gault and Lower Greensand are parts of an essentially continuous and conformable series ; their line of demarcation is often arbitrary and has no fixed time-relationship. In the Lewes–Eastbourne district of Sussex, for example, the basement-beds of the Gault are the age-equivalents of almost the whole of the Folkestone Beds of the Lower Greensand as developed at Folkestone, the *nodosocostatum*, *tardefurcata*, and *mammillatum* zones of the Albian all being represented in 3–4 feet of glauconitic sandy clay with phosphatic nodules. The presence of the *nodosocostatum* zone is here indicated by the *jacobi* fauna, the first authentic record of its occurrence in England since its discovery at Folkestone in 1939. Conversely, the sands which underlie the Gault in this part of Sussex are regarded as an expanded version of the bottom few inches of the Folkestone Beds at Folkestone and are compared with the sands below the nodule-bed with *H. jacobi* at Wissant, in the Bas Boulonnais.

The diachronous base of the Gault in East Sussex, previously thought to indicate transgressive overlap, may now be ascribed to the progressive assumption by the top beds of the Lower Greensand of the Gault facies as they extend towards the coast, thereby partly accounting for the rapid south-easterly thinning of the Lower Greensand in East Sussex. This hypothesis is advanced as the explanation for the apparent disappearance of the Folkestone Beds under Eastbourne.

Condensed and incomplete faunal successions are demonstrated in both areas and the significance of phosphatic nodule-beds in unravelling the relations of Gault and Lower Greensand is discussed. Some modifications of current views on the faunal sequence in the Folkestone Beds and basal Gault at Folkestone are introduced. The Lower Albian ammonite *Hypacanthoplites* is illustrated for the first time from a British occurrence.

---

[1] Communicated by permission of the Director of the Geological Survey and Museum.

INTRODUCTION

ALTHOUGH the beds at the junction of the Gault and Lower Greensand have been long familiar to geologists, they have never been explored thoroughly and what little work has been done on their age and relations suffers from inadequate knowledge of the fossils. Early observers like Topley were aware that it is not always easy to draw a rigid dividing line between the Lower Greensand and the Gault [**35**, p. 474*] and even Fitton, over a century ago, spoke of the two as having continuity of deposition [**10**, p. 117]. Nevertheless, the seemingly abrupt introduction of Albian fossils in the condensed beds at the base of the Gault, and the transgressive nature of these beds beyond the Wealden Area suggested to later generations an unconformity at this horizon, which in Britain had been taken as the plane of division between the Upper and Lower Cretaceous.

It is only in recent years that the discovery of Albian fossils throughout the Folkestone Beds, the topmost division of the Lower Greensand, has made it clear that in the Weald the base-line of the Gault does not mark any important break or boundary in the geological time-scale [**4**, **34**]. Indeed, renewed investigation now shows that to some extent basal Gault and Folkestone Beds are but different facies of a contemporaneous deposit, and that, as with the Gault and Upper Greensand, their line of demarcation has no fixed time-relationship. This fact can be best illustrated by comparing the Folkestone succession with that near the East Sussex coast, on the opposite side of the Wealden anticlinorium. Such a comparison will form a useful introduction to the study of the Folkestone Beds in other parts of the Weald, which the author proposes to make the subject of future papers.

Previous literature on the Folkestone area contains numerous references to the beds at the junction of the Gault and Lower Greensand ; in Sussex the beds have received less attention and have been studied in detail only by Dr. J. F. Kirkaldy [**15**].

The author gratefully acknowledges awards from the Daniel Pidgeon Fund of the Geological Society and the G. W. Young Fund of the Geologists' Association in aid of his researches. Major D. Courage of Chalvington and Mr. E. Lunt, County Surveyor for East Sussex, greatly facilitated the present investigation by giving access to land and permission to excavate. Specimens collected in the course of the field work are deposited in the Geological Survey Museum.

STRATIGRAPHICAL AND FAUNAL SUCCESSION

(a) Folkestone

(i) *General remarks*

Since the palaeontology of the Folkestone Beds and basal Gault at Folkestone will be dealt with fully elsewhere, it is necessary here

---

* For list of References, see p. 295.

ZONAL TABLE (after Spath 1943)			EAST CLIFF, FOLKESTONE, KENT.		
ZONES		SUBZONES			
MIDDLE ALBIAN (pars)	*HOPLITES DENTATUS*	*DIMORPHOPLITES NIOBE*	Bed III	4½ FT	LOWER GAULT (pars)
		ANAHOPLITES INTERMEDIUS	Bed II	4¼ FT	
		HOPLITES DENTATUS & HOPLITES SPATHI	Bed I (iii)	8 FT	
		HOPLITES BENETTIANUS	non — sequence		
	DOUVILLEICERAS MAMMILLATUM	*DOUVILLEICERAS INAEQUINODUM*	"Greensand Seam" Bed I (ii)	c.1 FT	
			"Sulphur band" Bed I (i)	c.1 FT	
		DOUVILLEICERAS MONILE	Price's 4th Division = Main *Mammillatum* Bed	6 FT	FOLKESTONE BEDS
			Top of Price's 3rd Division *Sonneratia kitchini* Bed	4 FT	
LOWER ALBIAN	*LEYMERIELLA TARDEFURCATA*	*LEYMERIELLA REGULARIS*	Main mass of Price's 3rd Division	50 FT	
		LEYMERIELLA ACUTICOSTATA	? Price's 2nd Division = Glauconitic Band	2 FT	
		LEYMERIELLA SCHRAMMENI	non — sequence		
	DIADOCHOCERAS NODOSOCOSTATUM	*HYPACANTHOPLITES JACOBI*	Basement-bed. Upper (*jacobi*) nodule band	1 FT	
			Basement-bed Lower (*rubricosus*) nodule band		
		HYPACANTHOPLITES NOLANI	? Sandgate Beds		

FIG. 1.—PART OF THE ALBIAN SUCCESSION AT EAST CLIFF, FOLKESTONE.

to take note only of those fossils which elucidate the zonal succession. The scheme of subdivision of the Albian put forward by Dr. L. F. Spath [27, p. 668][1] is adopted provisionally, and its application to the Folkestone section is illustrated in Fig. 1.

(ii) *Lower Greensand* (*Folkestone Beds*)

In the cliffs between the Harbour and Copt Point (East Cliff) the Folkestone Beds have an average thickness of sixty feet and were shown by Price to be capable of a fourfold division [23]. In recent years the present author has given these divisions zonal definition [4].

Price's first division, the basement-bed, comprises a foot of glauconitic, brown-weathering, clayey sand crowded with phosphatic nodules and small pebbles. The nodules tend to lie in two distinct bands. In the lower band are large balls of brown sandy phosphorite impregnated with iron. They carry a rich molluscan fauna with *Hypacanthoplites rubricosus* sp. nov. as the dominant ammonite. This is an ally of *H. subrectangulatus* (Sinzow) and *H. nolanisimilis* (Breistroffer) from the Lower Albian of Transcaspia and indicates an horizon slightly below that of the main development of *H. jacobi*, though above that of *H. nolani* at the very bottom of the Albian.

---

[1] M. Breistroffer has proposed an alternative scheme and given good reasons for assigning the *nodosocostatum* zone to the Aptian and the *mammillatum* zone to the Lower Albian [1].

The upper band contains lumps of black sandy phosphorite with rolled specimens of *Hypacanthoplites*. Many of the species in this band, such as *H. jacobi* (Collet), *H. elegans* (Fritel), and *H. spathi* (Dutertre), belong to the restricted *jacobi* subzone, but they are accompanied by undescribed species like *H. anglicus* sp. nov. which suggest affinity with forms of the *tardefurcata* zone. It is possible, therefore, that while still within the broader *jacobi* subzone, this upper band of nodules spans a slightly longer interval of time than do the strata which yield the classic *jacobi* fauna at Vöhrm and Algermissen, in Hanover.

This basement-bed testifies to long exposure on a sea-floor free of sedimentation [**4**, p. 365]. During this standstill in deposition at Folkestone the basal *tardefurcata* zone was laid down elsewhere.

Westwards the basement-bed expands rapidly. At Sandling Junction, Hythe, five miles north-west of Folkestone, it has passed into about seventy feet of strata with ammonites of the upper (*jacobi*) nodule-band distributed through the top ten feet; the remaining sixty feet consist of unfossiliferous sands which are shown by their field relations to be an expansion of the lower (*rubricosus*) nodule-band.[1] Across the Channel, at Wissant, the interval between the nodule-bed with *H. jacobi* and the correlatives of the Sandgate Beds is taken up by 15–20 feet of sands of Folkestone Beds aspect, which presumably are also of *rubricosus* age.

At East Cliff the basement-bed is overlain by two feet of dark green glauconitic clayey sand full of small pebbles and shell debris, but without ammonites. In 1939 this bed (Price's second division of the Folkestone Beds) was included in the *regularis* subzone, but recent collecting from an equivalent level at Newington, near Folkestone, has brought to light species of *Hypacanthoplites* which suggest a somewhat lower horizon. It seems likely that this glauconitic band represents the middle third of the *tardefurcata* zone, though in the absence of the diagnostic ammonite, one cannot be certain that it lies on exactly the same level as the beds with *Leymeriella acuticostata* on the Continent.

Price's third division of the Folkestone Beds commences with a band of calcareous glauconitic sandstone with clusters of small phosphatic nodules and grit strung along the top and bottom. *Leymeriella regularis*, *L. pseudoregularis*, and a giant species of

---

[1] Owing to confusion of some of the *jacobi* subzone ammonites from Sandling Junction and elsewhere with species of *Parahoplites* and *Acanthohoplites*, it was formerly believed that the *nolani* subzone of the Lower Albian and perhaps also the *aschiltaensis* subzone of the Upper Aptian were present in the Folkestone Beds [**4**].

Douvilleiceras are found either in the nodules or in the sandstone itself. Though replete with fossils of other groups, the succeeding fifty feet of sands and rock bands are very poor in ammonites. They have yielded fragments of large *Douvilleiceras* and the single example of *L. regularis* recorded by Dr. Spath [**31**]. These beds fall within the *regularis* subzone.

Complementary to the rapid expansion of the bands with *H. jacobi* and *H. rubricosus*, there is a marked westerly attenuation of the beds with *L. regularis*, which, locally, may disappear altogether less than five miles from Folkestone.

About ten feet below the base of the Gault at East Cliff is a thin, inconspicuous line of phosphatic nodules in which *Sonneratia kitchini* and, less frequently, *Douvilleiceras mammillatum* may be found. Since this horizon marks the entry of *D. mammillatum* and the exit of *L. regularis*, it is now taken as the lower limit of the *mammillatum* zone.

The main bed with *D. mammillatum* (*monile* subzone s.s.) is contained in the topmost six feet of sand, Price's fourth division of the Folkestone Beds. The fossils occur in a band up to a foot in thickness and from one and a half to four feet below the top of the sand. In East Wear Bay the bed declines to the shore and is washed over by the sea and here *D. mammillatum*, *D. monile* and *Beudanticeras ligatum* may be collected by the score. The associated hoplitid ammonites, such as *Protohoplites raulinianus* (d Orbigny), are less numerous but are better guides to horizon.

In the Geological Survey memoir on the Gault and Upper Greensand, Jukes-Browne concluded that on account of its Albian fossils this bed should be removed from the Folkestone Beds and attached to the Gault as " Bed 1a " [**13**]. Apart from historical considerations, this decision disregarded the fact that the Gault and the Folkestone Beds are lithological units, not chronological concepts based on palaeontology. A return to the older classification is doubly desirable now that the Folkestone Beds are known to be of Albian age throughout.

(iii) *Basement-beds of the Gault*

The base of the Gault is very clearly exposed for over half a mile in the cliff east of Folkestone Harbour. It is most accessible at Copt Point and on the adjoining foreshore on the southern side of East Wear Bay. The following section may be seen in the cliff at Baker's Gap, just west of Copt Point :—

Gault

		ft.	in.
	Gault clay to top of cliff		
12.	*Bed 1* (iii), a, Dark grey clay with *A. intermedius* above and *H. dentatus* below	7	6
11.	b, Line of phosphatic nodules full of *H. dentatus*, *H. spathi*, etc. ... ... 1 in. to		4
10.	*Bed 1* (ii) " *Greensand Seam* " : dark green sandy clay (about 33 per cent glauconitic sand) with phosphatic nodules, mostly		

			ft.	in.
	septarian, disposed roughly in two lines. Occasional small quartz pebbles	1 ft. to	1	3
9.	*Bed 1* (i) " *Sulphur Band* " : an indurated layer of phosphatic nodules, the nodules veined and encrusted with pyrites and embedded in a matrix of clayey greensand, the whole coloured yellow and reddish-brown by decomposition products.[1] Two distinct concentrations of nodules recognisable. Fossil wood.	1 ft. to	1	3
	Folkestone Beds			
8.	Coarse grey sand, somewhat clayey at top	1ft. 6in. to	2	0
7.	*Main mammillatum bed* : seam of coarse sand and grit with numerous phosphatic nodules	6in. to	1	0
6.	Very coarse sand and grit	1ft. to	1	6
5.	Incoherent yellowish greensand		3	0
4.	Hummocky rock band of indurated sand and grit		1	3
3.	Very coarse sand and grit with small pebbles and shell fragments		2	2
2.	*Sonneratia kitchini bed* : line of small phosphatic nodules scattered through coarse yellowish sand. Wisps of grey clay	4in. to		8
1.	Very coarse sand and grit			
	Yellowish greensands and rock bands to base of cliff.			

Judged by its lithology the " Sulphur Band " is as closely linked with the stratum below as with that above ; but since it stands out prominently in the cliff, forming a natural base to the clays, it is the bed most readily taken as the commencing point of the Gault. It is traceable over a wide area in the Folkestone neighbourhood and is present at Wissant on the opposite coast of France. This is the " phosphate-of-lime bed " and " junction-bed " of Mackie [**19**, **20**], the " phosphate-bed " and the " iron seam " of De Rance [**6**, **7**], Price's " first line of phosphatic nodules " [**25**, p. 10], and the " pyritous band " of Lamplugh [**17**, p. 8] and other authors.

Although Jukes-Browne gives the French geologist A. Gaudry the credit for pointing out the existence of the *mammillatum* zone at Folkestone in 1859 [**13**, p. 43], the occurrence of the zone fossil in the " Sulphur Band " (" phosphate-of-lime bed ") had been noted already by Mackie three years before [**19**]. Furthermore, in 1860 Mackie described and illustrated a section of the cliff at Folkestone, making it perfectly clear that this ammonite occurs both in the " Sulphur Band " and in the sandy stratum below [**20**, p. 87, Fig. 11]. Unfortunately, this observation, too, was overlooked or discountenanced by all later investigators of the Folkestone Gault ; De Rance in 1868 explicitly placed the " Sulphur Band " in the *dentatus* [*interruptus*] zone and restricted the *mammillatum* zone to the bed below [**7**], and this procedure was followed by Price [**23**], Jukes-Browne [**13**], Lamplugh [**17**] and, in more recent years by Dr. Spath [**28**, **29**]. In 1923 the last author further assumed that there was a gap in the succession between the main bed of *D. mammillatum* and the " Sulphur Band " corresponding to the *inaequinodum* and *benettianus* subzones of the west country [**28**, **29**], a view he appears to maintain [**27**, p. 734].

---

[1] The yellow material from which the " Sulphur Band " takes its name is derived from the decomposition of the pyrites. Radley (*The Naturalist*, April 1929, p. 145) found it to contain ferric chloride, sodium chloride, and magnesium chloride.

Collecting by the author at Folkestone [**32**, **3**] and by MM. J.-P. and P. Destombes at Wissant [**8**] has confirmed the presence of fossils of the *mammillatum* zone in the " Sulphur Band ". The ammonites obtained from this bed at Folkestone include *D. mammillatum* (Schlotheim) Spath, *D. monile* (J. Sow), *Beudanticeras ligatum* (Newton and J.-Browne), *Cleoniceras* cf. *quercifolium* (d'Orb.), *Pseudosonneratia* sp., and several undescribed forms of *Protohoplites*. The last are of interest as showing that the " Sulphur Band " lies upon a slightly higher palaeontological horizon than that of the main bed of *D. mammillatum* (see p. 295) and that this bed should be regarded as marking a distinct faunal band within the broad *monile* subzone. Clearly the " Sulphur Band " is a *remanié* deposit, but since all the fossils are forms of the *mammillatum* zone with no admixture of species of the zone above, it is difficult to accept Dr. Spath's suggestion that they are probably derived [**27**, p. 734] and that the Gault at Folkestone probably rests unconformably on the Folkestone Beds [**27**, p. 741].

According to Price the greensand seam which overlies the " Sulphur Band " contains two lines of phosphatic nodules " in which *A. interruptus* occurs frequently " [**23**, p. 142] and this statement is repeated by Jukes-Browne [**13**, p. 74]. In actual fact the greensand seam itself is almost barren of macroscopic fossils and it is in the single line of nodules at the junction of this seam with the clays above that ammonites of the " *interruptus* " (i.e. *dentatus*) group abound. Dr. Spath, it is true, has recorded " forms of *Hoplites*, including *H. dentatus* " from this seam [**27**, p. 734 footnote], but re-examination of the material on which this record is based does not confirm the presence of *H. dentatus* or any of its contemporaries. There can be little doubt that these are in fact the ammonites which De Rance found in the greensand seam and styled a form of *Ammonites deshayesii* [**7**, p. 167]—the same *A. deshayesii* indicated at this horizon in Topley's *Geology of the Weald* [**36**, p. 146]. These ammonites are here considered to be comparable with *Pseudosonneratia laffrayei* Breistroffer (see p. 293) and to indicate an horizon approximately equivalent to that of *Douvilleiceras inaequinodum*.

Chapman drew attention to the great length of time necessary for the formation of the greensand seam [**5**, p. 307] and it is possible, though unlikely, that it is in part of *benettianus* age. Elsewhere in Kent a foot or so of grey-green sandy clay forms a passage-bed between the greensand seam and the dark clays with *H. dentatus*; the absence of this bed at Folkestone accounts for the abrupt change in lithology above this seam and confirms that the succession is here incomplete.

Thus it is seen that the basement-beds of the Gault at Folkestone fall within the *mammillatum* zone of the current zonal classification, the greensand seam lying on the same general horizon as the beds with *D. inaequinodum* in the west country, while the "Sulphur Band" may be bracketed with the top part of the Folkestone Beds in a broad subzone of *D. monile*. A non-sequence involving the basal *dentatus* zone (*benettianus* subzone) appears to coincide with the contact of the greensand seam and the *dentatus-spathi* nodule-bed, two or three feet above the base of the Gault; but there is no definable gap in the sequence at the actual junction of the Gault and Lower Greensand, and it follows that the two formations are here conformable.

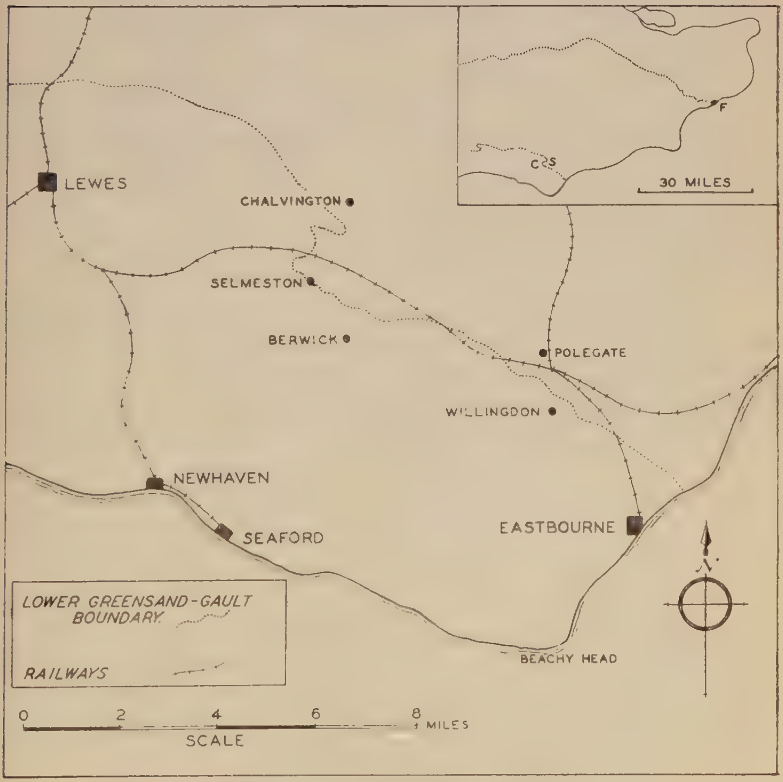


FIG. 2.—SKETCH-MAP OF PART OF EAST SUSSEX, with inset map showing the relative positions of the Chalvington-Selmeston district (CS) and Folkestone (F).

(b) East Sussex

(i) *Field Evidence*

In East Sussex the Gault, developed almost to its full extent, rests on an attenuated, south-easterly dwindling thickness of Lower Greensand. The natural starting point for a study of the basement-beds of the Gault in this area is the large sandpit at Manor Farm, 300 yards north-west of Chalvington Church, which formerly exposed the basal nodule-bed for a distance of nearly 200 yards [**15**, p. 520]. Although this pit has been long abandoned and is now flooded and overgrown, it still provides the key section of the district. Dr. Kirkaldy described the succession as follows :—

			ft.	in.
	Soil			
	Gault			
8.	Green glauconitic sandy clay with lenticles of reddish-brown clay	1ft. to	1	6
7.	Discontinuous layer of white phosphatic nodules and pieces of bored wood	0in. to		3
6.	Green glauconitic sandy clay	1ft. 6in. to	3	0
5.	Continuous layer of nodules and wood [in matrix as Bed 6]	3in. to		6
	Folkestone Beds			
4.	White medium sands faintly speckled with grains of glauconite	1ft. 6in. to	3	0
3.	Brown sand with scattered quartz pebbles up to a quarter of an inch in diameter		2	0
2.	White sand as in Bed 4		6	0
1.	Greyish, slightly clayey sand with a few soft nodules of ironstone	Seen	2	0

Mr. Osborne White, who does not appear to have seen the beds in a clear section, assigned the lower nodule-bed (Bed 5) provisionally to the Lower Greensand [**38**, p. 35] ; but Dr. Kirkaldy was able to show that the most marked lithological change takes place below this bed and that there could be little hesitation in regarding it as the base of the Gault [**15**, p. 521].

Only Beds 4 to 8 of the section are now above water, and these may be inspected only for a distance of about twenty yards. Rootlets from the soil penetrate the beds and leave pipings of green clayey material in the top few inches of the Folkestone Beds. These may be the " borings " noted by a previous observer [**15**, p. 521].

Dr. Kirkaldy recorded the ammonite *Douvilleiceras* aff. *mammillatum* (Schlotheim) from the phosphatic nodules in this pit, but, as in the other sections he described, did not state the particular bed from which each specimen came. The importance of this detail may be judged from the following list compiled from specimens collected strictly *in situ* from the present exposure :—

(a) Upper nodule-bed (Bed 7 of section)

Ammonoidea. *Leymeriella tardefurcata* (Leymerie) d'Orbigny sp., *Leymeriella regularis* (Bruguière) d'Orbigny sp., *Leymeriella* aff. *regularis* (Plate 14, Fig. 11), *Sonneratia* cf. *sarasini* Jacob, *Sonneratia* aff. *parenti* Jacob,

Cleoniceras aff. *baylei* (Jacob), *Douvilleiceras* aff. *mammillatum* (Schlotheim) Spath, *Douvilleiceras* sp., *Beudanticeras ligatum* (Newton and Jukes-Browne).
Lamellibranchia. *Neithea* (*Neitheops*) *quinquecostata* (J. Sowerby), *Martesia prisca* (J. de C. Sowerby) in wood, *Trigonia* sp.

(b) Lower nodule-bed (Bed 5 of section)

Ammonoidea. *Hypacanthoplites jacobi* (Collet), *Hypacanthoplites clavatus* (Fritel), *Hypacanthoplites* aff. *elegans* (Fritel) (Plate 14, Fig. 12), *Hypacanthoplites* cf. *spathi* (Dutertre), *Hypacanthoplites* spp. indet.
Lamellibranchia. *Exogyra obliquata* (Pulteney) (= *E. conica* J. Sowerby), *Gervillella* sp., *Chlamys robinaldina* (d'Orbigny), *Entolium orbiculare* (J. Sowerby), *Venilicardia* sp., *Martesia prisca* (J. de C. Sowerby) in wood, cf. "*Turnus*" *amphisbaena* (Goldfuss).
Brachiopoda. "*Rhynchonella*" cf. *sulcata* Price *non* Parkinson.
Pisces. Scales of undetermined genus and species.

The ammonites from the lower nodule-bed are of great interest, for they show that the bottom of the Gault in this section lies in the *jacobi* subzone of the Lower Albian. This was somewhat unexpected, for the only previous authentic record of the *jacobi* fauna in England[1] is from a much lower stratigraphical level, i.e. the base of the Folkestone Beds at Folkestone [**4**]. In these circumstances it is necessary to enquire whether the fossils in the base of the Gault at Chalvington are derived.

The fossils are phosphatised and are obviously native to the nodules, which consist for the most part of hard, dark-coloured lumps of phosphorite, much rolled and battered. A few whitish, friable specimens in the same bed seem to have reached (as noted by Dr. Kirkaldy) a less complete stage in the process of phosphatisation. When split open, the nodules exhibit a collophane groundmass studded with glossy sand-grains, particles of glauconite, and small pebbles of quartz, matching almost perfectly the nodules found at the base of the Gault in parts of Kent and Surrey. So good is the agreement between the detrital material in the nodules and that of the bed in which they lie, that it is difficult to avoid the conclusion that the nodules are merely calcium-phosphate-cemented lumps of the original sea-floor which have survived as a *remanié* bed *in situ*. The view that this nodule-bed has been formed by some agency on the spot was taken also by Mr. Osborne White [**38**, p. 35], and from these observations it is concluded that the *jacobi* fauna is here indigenous.

The upper bed of phosphatic nodules yields an entirely different set of ammonites; these indicate that this bed is a condensed *remanié* of the topmost part of the *tardefurcata* zone (*regularis* subzone) and the bottom part of the *mammillatum* zone. Although they are separated by no more than three feet of strata, there is thus a great difference in age between the two seams of phosphatic nodules. Unfortunately, the intervening bed of green sandy clay carries no intrinsic evidence of age, but since there appears to have been a long period of time prior to its formation during which the nodules with *H. jacobi* were scoured out and rolled on the sea-bed, we may infer a missing interval at the base of the *tardefurcata* zone.

---

[1] The fossils from the Folkestone Beds of Farnham (Surrey) attributed to the *jacobi* subzone by the brothers Wright [39] and Dr. Spath [27, p. 739] are considered by the author to belong to a higher horizon.

In a large sandpit at Poundfield Corner, 700 yards south-east of Chalvington Church, the following section was seen by Dr. Kirkaldy [**15**, p. 521] :—

Loamy soil

	Gault	ft.	in.
6.	Green glauconitic clayey sand with a thin layer of nodules at its base	1	0
5.	Current-bedded glauconitic coarse sand. The foresets dip at 27° from the north-west and are picked out by glauconite grains and white algal markings	1	6
4.	Well-bedded, greenish-brown coloured clayey sand with a considerable amount of glauconite	1	6
3.	Thin layer of small nodules ... 1in. to		2
	Folkestone Beds		
2.	Buff, slightly clayey coarse sand	1	0
1.	White speckled fine to medium sand ... Seen	6	0

The phosphatic nodules furnished him with a number of fossils, among which Dr. Spath recognised the following ammonites : *D.* aff. *mammillatum* (Schloth.), *B. ligatum* (Newton and J.-Browne), *Sonneratia kitchini* Spath, *Sonneratia* sp. nov., *Sonneratia* sp. indet., and *Leymeriella* (?) sp. nov.

The site of this pit is now occupied by a lake and no section has been accessible for many years, but an old spoil heap was found above water, excavated, and the nodules sifted out. In addition to lamellibranchia, they provided *D. mammillatum* (Schloth.), *D.* sp., *Beudanticeras* ?, *Sonneratia* sp., *Hypacanthoplites* cf. *elegans* (Fritel), and *Hypacanthoplites* sp. indet.

These ammonites confirm the evidence from Manor Farm that the nodules lie upon two distinct palaeontological horizons. The species of *Douvilleiceras*, *Sonneratia*, and *Beudanticeras* may be assigned to the layer of nodules at the base of Bed 6 (=Bed 7 of Manor Farm), while the species of *Hypacanthoplites* almost certainly came from Bed 3 (=Bed 5 of Manor Farm).

Through the courtesy of Dr. Spath the writer has been able to examine at the British Museum (Natural History) some of the ammonites collected by Dr. Kirkaldy. They include a small fragment of *Hypacanthoplites* (C 36492) which appears to be the basis of the record of *Leymeriella* (?) from this locality.

At Selmeston, about a mile and a half south-south-west of Chalvington, the bottom bed of the Gault and the underlying sands may be seen in the brow of a very old sandpit about 150 yards south-east of the Church. The section is detailed below :—

			ft.	in.
	Soil with flints and pieces of chalk			
	Gault			
4.	Olive-green sandy clay, weathering brown	Seen	1	0
3.	Band of phosphatic nodules	3in. to	0	6
2.	Glauconitic clayey sand, weathering reddish-brown		0	6
	Folkestone Beds			
1.	Pale yellow sands, faintly speckled with grains of glauconite, somewhat argillaceous in places	Seen	6	0

Only the lower of the two nodule-beds found at Chalvington is exposed in this section and owing to the proximity of the soil the fossils are in poor condition. Besides fossil wood, which is plentiful in all exposures of these beds, they include specimens of *Hypacanthoplites* and various bivalves.

In a sandpit by the roadside at the corner of Selmeston Churchyard a section similar to that given above was described by Bristow [**2**, p. 127]. This is thought to be the same section which came under the observation of Mantell and from which he obtained the pine-cone named by him *Zamia sussexiensis* [**22**].

The lithological characters of the top beds of the Lower Greensand are very clearly displayed in the large sandpit 300 yards south-east of Selmeston Church, where the beds are worked to a depth of about fifteen feet. The sands are predominantly pale yellow, buff, and grey in colour, evenly bedded and of fine texture. Buff sand shot with veins of dark green sandy clay like that at the bottom of the Gault was visible near the floor of the pit in 1949, and rafts of mauve and grey clay were seen in the three feet of sand above. For the next ten feet the sand carries argillaceous matter only in wisps. This part of the section is the source of the friable ironstone nodules lying about the pit. Glauconite is disseminated throughout the sands and is particularly abundant just below the base of the Gault.

This section does not show the contact with the Gault in place, but in the south-east corner of the pit the sands are overlain by a bed of phosphatic nodules—a residuum from the erosion of the feather-edge of the Gault. Were it not for the presence occasionally of a flint or some other foreign body among the nodules, the bed could easily be mistaken for the base of the Gault *in situ*. *Hypacanthoplites* and other fossils were obtained from the nodules.

Mr. Osborne White mentions that coarse brown sand with phosphatic nodules containing wood is turned up by rabbits on the site of old diggings one-third of a mile west of the cross-roads south of Berwick Station [**38**, p. 36]. No exposure exists at this locality today, but a specimen of *Leymeriella* from the collection of Daniel Sharpe (1806–56) labelled " Berwick Common, near Lewes " is in the Geological Survey Museum. This is the specimen on which Dr. Spath based his original record of *L. regularis* from Sussex [**30**, p. 424].

Topley [**36**, p. 127] described the Gault with its phosphate bed and fossil wood lying on the sands of the Lower Greensand in the railway cutting west of Polegate Station, south of Wooton Farm, about three miles east of the last exposure, thus :—

	ft.	in.
Green, rather clayey sand	1	6
Phosphatic nodules and wood	0	4
Red Sand	1	0
Sand, setting [*sic*] greenish below		

The section is no longer visible, but clearly agrees with those of the Chalvington–Selmeston district, the bed of nodules and wood corresponding to the lower (*jacobi*) nodule-bed at Manor Farm and Poundfield Corner, while the underlying " red sand " may be compared with the thin seam of reddish-brown clayey sand below the nodule-bed at Selmeston.

In the north side of the cutting on the Eastbourne–Polegate road, opposite Willingdon Mill and half a mile south of Polegate Railway Station, Dr. Kirkaldy found " the nodules . . . clearly exposed, dipping eastwards at 5°, beneath the typical black clays of the main mass of the Gault and resting on a clean-cut surface of the Folkestone Sands " [**15**, p. 523]. He recorded *Douvilleiceras* aff. *mammillatum* and *Leymeriella tardefurcata* from the nodules.

On a preliminary visit to this site the author found the cutting grassed over and it was necessary to obtain permission from the local authority to reopen the section. Trenches were cut in a vertical line at two points in the north embankment,[1] permitting the following succession to be seen :—

		ft.	in.
	Gault		
7.	Olive-green glauconitic sandy clay, passing up into the soil	0	10
6.	Bluish clay with very little sand or glauconite ; sparse buff-coloured phosphatic nodules	3	0
5.	Line of small black-hearted phosphatic nodules, some veined with pyrites	0	2
4.	Bluish clay, slightly sandy and glauconitic ; one or two nodules as in Bed 6 ; presence of pyrites in finely divided state indicated by yellowish streaks	2	3
3.	Olive-green glauconitic sandy clay with small pebbles of quartz (hard digging)	3	0
2.	Band of phosphatic nodules, up to 6in. in length, and abundant fossil wood 3in. to	0	6
	Folkestone Beds		
1.	Yellow-green glauconitic sands, slightly micaceous, with wisps of mauve and grey clay, passing down into yellowish sands with little glauconite Seen	6	0

The bluish clays of Bed 4 could be seen in a bare patch on the opposite embankment.

Opportunity for fossil collecting was limited, but the following specimens (all phosphatic) were obtained either from the excavations in the north embankment or from a natural exposure in the south embankment :—

---

[1] In his investigations at Willingdon the author was assisted by Mr. T. B. Smart.

Bed 6 : *Douvilleiceras* sp., *Beudanticeras* aff. *ligatum* (Newton and J.-Browne), indeterminate lamellibranchs (all in a single nodule 4 inches above Bed 5).
Bed 5 : Indeterminate gastropod.
Bed 4 : *Leymeriella* spp. juv., including *L.* cf. *regularis* (Brug.) d'Orb. sp.
Bed 2 : *Hypacanthoplites* sp., *Martesia prisca* (J. de C. Sow.) (in wood), vertebral disc 3½in. in diameter, much rolled (? *Ichthyosaurus*).

In this section the bottom beds of the Gault (Beds 2 and 3) were found to be similar to those at Chalvington and Selmeston. Even if palaeontological evidence were lacking, it could scarcely be doubted that the nodule-bed overlying the Folkestone Beds at Willingdon is the same bed which contains ammonites of the *jacobi* subzone farther to the west. On the other hand, the upper nodule-bed of Chalvington (with the *tardefurcata-mammillatum* fauna) does not maintain its identity in the Willingdon section. Here the glauconitic band (Bed 3) shades off rapidly into the bed above with no trace of a nodule-bed at the junction, though isolated nodules were found in the clays above. The few fossils obtained from above Bed 3 suggest that both the *tardefurcata* and *mammillatum* zones are present but discrete. Thus it is permissible to regard the upper nodule-bed at Chalvington as a *remanié* derived from the destruction of strata equivalent to Beds 4–6, and perhaps higher beds, at Willingdon.

As regards the fossils previously recorded from this locality, it now appears improbable that they did in fact have their origin in the basal nodule-bed. Presumably they were picked up loose and assigned to this bed on account of their phosphatic mode of preservation.

Mantell's reference to a bed of greensand abounding in fossil wood at Willingdon [**21**, p. 76] clearly applies to Beds 2 and 3 of the present section.

Between Willingdon and the coast the Lower Greensand and the Gault are largely hidden by alluvial deposits. " Coarse sand and small phosphatic nodules with glauconite grains " were described by Reid as occurring beneath the Gault in a well-section three-quarters of a mile north of the pier at Eastbourne [**26**, p. 2], but it is doubtful whether the Folkestone Beds persist south-eastwards much beyond Willingdon. They had disappeared already at Willingdon Laundry, 150 yards north of Hampden Park Station, where a well proved only loams of the Sandgate Beds type between the Gault and the Weald Clay [**16**, p. 107]. Eight feet of yellow sand, presumably representing the Folkestone Beds, are reported at Hydneye, 650 yards north-north-east of the last locality [**16**, p. 107], but the deep wells at Eastbourne have furnished no evidence of this division of the Lower Greensand [**9**, pp. 92–3, 140].

In the absence of suitable exposures with fossils, it is not known how far the glauconitic band with its fossiliferous nodule-beds above and below extends along the outcrop *west* of Chalvington and Selmeston. Mr. Osborne White has drawn attention to the presence of a green bottom bed to the Gault in most of the published well-sections in the area covered by the Lewes memoir [**38**, p. 38], and Dr. Kirkaldy has shown that glauconitic sandy clay with phosphatic nodules is present at the base of the Gault to beyond Steyning, fifteen miles west of Lewes [**15**, p. 532]. Evidence of age, however, was found only at West Winds Poultry Farm, a mile north of Steyning, where the nodules contained *D.* aff. *mammillatum* and *B. ligatum* to the exclusion of other ammonites [**15**, p. 527], indicating an horizon within the *mammillatum* zone no lower than Bed 6 of the Willingdon section. Elsewhere in the Steyning district Dr. Kirkaldy has described a gradational change in lithology from the Folkestone Beds to the Gault [**15**, p. 527][1] but in none of these sections has the *tardefurcata* or *jacobi* horizons been recognised.

(ii) *Summary of Field Evidence*

In the Chalvington–Selmeston district of Sussex, east of Lewes, the basement-beds of the Gault comprise three divisions :

3.	Phosphatic nodule-bed with *remanié* fossils of the topmost *tardefurcata* zone (*regularis* subzone) and the lowest part of the *mammillatum* zone	a few inches only
2.	Glauconitic band : predominantly sandy clay. No fossils	about 3 feet
1.	Phosphatic nodule-bed with *remanié* fossils of the upper *nodosocostatum* zone (*jacobi* subzone)	a few inches only

Well-records and open sections show that the glauconitic band with an underlying nodule-bed is continuous and maintains much the same characters along the outcrop to the coast at Eastbourne. At Willingdon, north-west of Eastbourne, the top division is replaced by six feet or more of bluish clays and green sandy clays with sparse phosphatic nodules ; at this locality the *tardefurcata* and *mammillatum* elements of the fauna appear to be discrete.

Between Lewes and Willingdon the Gault rests on pale, slightly clayey sands of the Folkestone Beds. The presence of these sands beyond Willingdon is doubtful : they have not been identified at Eastbourne.

CORRELATION AND INTERPRETATION OF THE SECTIONS

(a) General Comparison

Vertical sections of the Folkestone Beds and basal Gault in the Chalvington–Selmeston district of Sussex and at East Cliff, Folkestone, are illustrated in Fig. 3.

---

[1] Reference to the literature of the same general area will show that even when the transition from the Lower Greensand to the Gault is effected within a very small vertical distance, there is, nevertheless, a gradation from one to the other, the bottom of the Gault consisting of coarse sands with streaks and lenticles of clay [15, pp. 528–9] or yellow loamy sand [37, p. 29], while occasionally friable phosphatic concretions are found in the top few feet of the Folkestone Beds [37, p. 17].

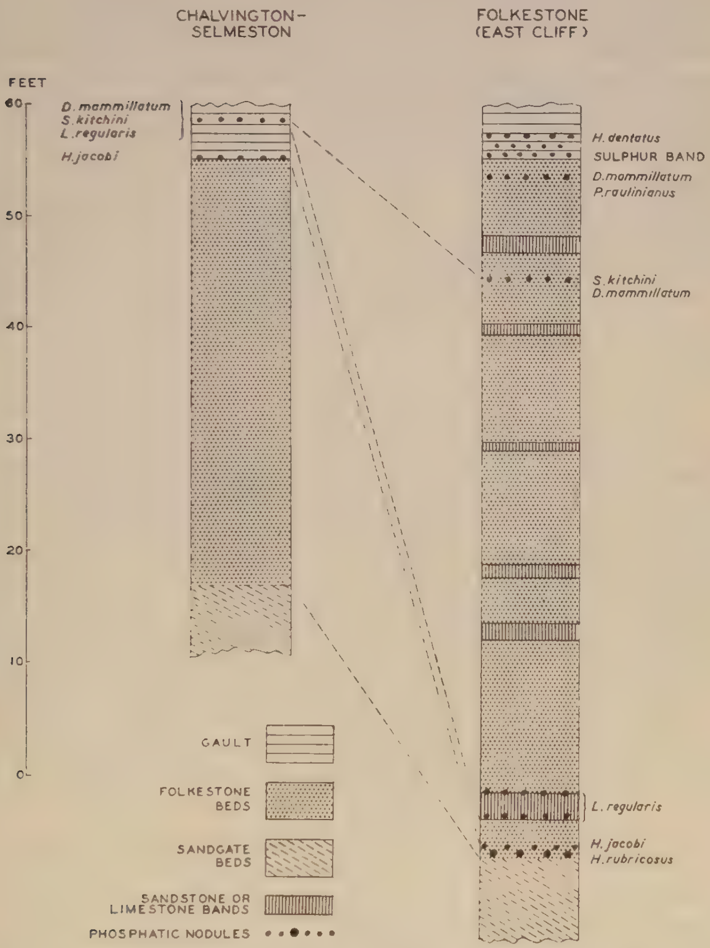


FIG. 3.—Comparative sections of the basal Gault and Folkestone Beds of the Chalvington-Selmeston district of Sussex and of Folkestone, Kent.

It is apparent from the distribution of the zone fossils that the basement-beds of the Gault in East Sussex cannot be correlated with their namesakes at Folkestone ; instead, within a thickness of little more than three feet, they contain the age equivalents of almost the whole of the Folkestone Beds of Folkestone.

The presence of *Hypacanthoplites jacobi* and allied species in the nodule-bed at the bottom of the Gault in East Sussex necessitates that this bed be equated with the upper portion of the basement-bed of the Folkestone Beds at East Cliff. As in the Folkestone district, the *jacobi* fossils in Sussex are found in a rolled condition; this and other circumstances indicate that in the marginal areas of the basin the *jacobi* hemera was followed by a halt in sedimentation during which the previously deposited sediment was reworked and winnowed by submarine agencies. This interval accounts for the absence of fossils of the basal *tardefurcata* zone (*schrammeni* subzone) in the localities investigated.

Both at Folkestone and in East Sussex the nodule-bed with *H. jacobi* is succeeded by two or three feet of highly glauconitic strata, this thin green band being all that denotes the long period of time that elapsed before active deposition was re-established over the area. Its formation may be dated as approximately middle *tardefurcata* time, though in the absence of fossil evidence this cannot be assumed to have been strictly contemporaneous at both places.

In East Sussex evidence indicates that the *regularis* and lower *mammillatum* subzones consisted originally of an alternating series of bluish sandy clays and clayey greensands with phosphatic nodules, as is now found at Willingdon; but in the Chalvington area it has been reduced to a single line of nodules. The principal elements of the fauna are *Leymeriella regularis*, *Sonneratia kitchini* and *Douvilleiceras mammillatum*. At Folkestone the range of strata indicated by this association corresponds to Price's third division of the Folkestone Beds, about fifty-five feet of strata. It is possible that this nodule-bed at Chalvington embraces also the main level of *D. mammillatum* at Folkestone and that collection failure is responsible for the absence of fossils diagnostic of this horizon. There is, however, no positive evidence for the presence of this part of the *mammillatum* zone in the bottom few feet of the Gault east of Lewes, still less the higher beds of the *mammillatum* zone which commence the Gault succession at Folkestone.

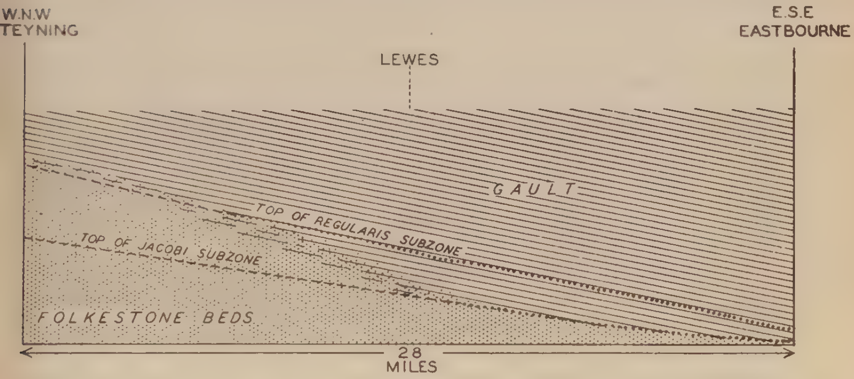
(b) Stratigraphical Relations of the Gault and Lower Greensand in East Sussex

From the fact that the basement-beds of the Gault between Lewes and Eastbourne contain fossils of the *tardefurcata* and *mammillatum* zones, while west of Lewes they yield only a normal *mammillatum* fauna, Dr. Kirkaldy was able to show that the base of the Gault in Sussex is diachronous. He has interpreted this as proof of transgressive overlap by the Gault and has implied that a regression and readvance of the sea took place in the area after the deposition of the Lower Greensand. The mixed beds of sand and clay at the junction of the two formations west of Lewes he has explained as due to agitation of the top of the Lower Greensand during the initial stages of deposition of the Gault [**15**, p. 535].

As has been indicated above, however, the basement-beds of the

Gault in the extreme east of Sussex contain two distinct fossiliferous bands, the lower of which lies in the *jacobi* subzone of the *nodosocostatum* zone. Diachronism is, therefore, much more pronounced than formerly supposed.

It has been shown also that although the broad *jacobi* subzone is condensed into the basal foot of the Folkestone Beds at Folkestone, it swells out rapidly along the outcrop and in mid-Kent makes up the greater part of this division of the Lower Greensand. It is only because the uncondensed facies of the Folkestone Beds does not favour the preservation of fossils that the Weald-wide extension of the two Lower Albian zones has hitherto escaped recognition. At all events, it is clear that while the *jacobi* and *regularis* faunas were being buried in clayey deposits on the sea-bottom in East Sussex, the same sea in neighbouring areas was receiving the sandy detritus now constituting the Folkestone Beds.



G. 4.—Diagram Showing the Suggested Relationship of the Gault to the Lower REENSAND (Folkestone Beds) in East Sussex. (Vertical distances greatly exaggerated and not to scale).

The conclusion is inescapable, therefore, that in East Sussex there is no transgressive overlap at the junction of the Gault and Lower Greensand, but only a lateral change of facies, the top beds of the Lower Greensand passing into the Gault as they extend south and east along the outcrop (Fig. 4). The ammonites found at the base of the Gault at different localities do not date the arrival of an advancing sea, but merely the onset of conditions suitable for the preservation of fossils.

An increase in the amount of clay and glauconite in the Folkestone Beds east of the River Ouse has been noted by previous observers [**16**, p. 105, **38**, p. 35]. It would appear that this increase is progressive as the beds are followed to the coast, being especially marked in the higher members, so that east of Lewes the term Gault, as denoting a predominance of clay, becomes applicable to these beds. This lateral change of facies helps to account for the rapid thinning of the Folkestone Beds from about 100 feet at Steyning to less than ten feet a mile north-west of Eastbourne. The apparent absence of the Folkestone Beds under Eastbourne itself suggests that the process of assimilation of these beds by the Gault is here complete.

Once it is accepted that the Gault and Lower Greensand in East Sussex are conformable, the gradational change in lithology from one to the other noted in the area west of Lewes finds a straightforward explanation. Such an explanation would seem to have been preferred by Mr. Osborne White, who suggested that in this area both the basal Gault and the top few feet of the Folkestone Beds might belong to the *mammillatum* zone [**37**, p. 24]. East of Lewes the passage beds between the Gault and the underlying sands have been condensed and partially obliterated by subsequent reworking of the sea-bed, but it is not believed that a time-gap of any magnitude now separates the two series (see p. 289). It seems probable that these sands were laid down wholly or in part during the time of formation of the nodules with *H. rubricosus* at Folkestone, and are thus comparable with the sands below the *jacobi* horizon at Sandling Junction, Hythe, and with the sands in the same position at Wissant, in the Bas Boulonnais.

The southerly or south-easterly overstepping of the Hythe Beds by the Sandgate Beds near Berwick and the thinning-out of the whole of the Lower Greensand in that direction support the belief that in Lower Greensand times East Sussex lay on the margin of a deposition area, and Dr. Kirkaldy has given grounds for inferring the presence during these times of a land-mass with its northern limit situated just south of Beachy Head [**14**, pp. 301–2]. Yet in East Sussex the Gault attains the unusual thickness of over 300 feet. These facts invite the suggestion that this land-mass was a source of supply of argillaceous material and that the early onset of Gault conditions in the extreme east of Sussex is attributable to its influence —an influence that was destined to become dominant in later Albian times over the whole of the southern part of the basin of deposition.

PHOSPHATIC NODULE-BEDS AND THE PALAEONTOLOGICAL RECORD

The numerous pauses in deposition and oscillations in the submarine erosion level which attended the Albian transgression have left their mark all around the Weald in the concentrations of glauconite and phosphatic nodules at certain horizons. To the palaeontologist the phosphatic deposits have special import, since in a formation composed mainly of incoherent materials phosphatisation acts as a natural preservative of fossils. In the sandy strata below the Gault the phosphatic nodule-beds alone maintain the continuity of the organic record, providing an epitomised but readable version of a story that is illegible in its more expanded form. Some observations on the origin and mode of occurrence of these beds and their significance in stratigraphical analysis, with special reference to the East Sussex sections, may, therefore, be apposite.

At the junction of the Gault and Lower Greensand phosphatic nodules tend to be aggregated into seams, and two, three, or more such seams may be spaced at intervals varying from a few inches to several feet. The matrix of the nodules is a mixture of sand and clay, usually rich in glauconite. Generally the sequence becomes more sandy in descending and the sands which underlie the bottom seam of nodules may still contain clay and glauconite in appreciable quantities, so that often it is difficult to decide at what point to take the junction. Careful examination will frequently reveal the presence of whitish, friable inclusions in the sand for a foot or two below the bottom nodule-bed. These inclusions give a strong reaction for phosphorus and are obviously phosphatic nodules in an early stage of formation. The exposures at Parson's Corner, near Snodland, and Wrotham Heath, Kent, and at Wrecclesham, Surrey, provide good examples of this incipient phosphatisation of the sands at the top of the Folkestone Beds. In these and similar sections it is clear that the onset of phosphatisation was gradual and that there is a decided passage from the Lower Greensand to the Gault.

On the other hand, certain sections, like those in East Sussex, show the basal nodule-bed resting on the sands of the Folkestone Beds with a sharp, clean-cut junction. The amount of glauconite and clay in the sand is insufficient to impair the lithological contrast and the closest scrutiny of the sand will fail to detect phosphatic inclusions such as those described above.

The late Mr. F. Gossling explained the gradual passage of the top part of the Folkestone Beds up into the clayey sands and sandy clays at the base of the Gault in the Reigate area of Surrey by invoking deep storm wave action, whereby previously deposited sands were mixed with the first layers of mud brought in by the Gault sea. He was thus of the opinion that the passage was " more apparent than real" [**11**, p. 257]. This hypothesis has been applied by other workers to sections which show a similar gradational change from Folkestone Beds to Gault. In the author's view, however, these beds of mixed lithology at the common limit of the two series are true passage beds and it is sections such as those in East Sussex which are deceptive.

Although the genesis of phosphatic deposits is still largely a subject for speculation, it is generally agreed that occurrences of phosphatic nodules in marine sediments are connected with conditions of slow or arrested deposition. Under such conditions the compounds of phosphorus normally dispersed throughout the accumulating detritus may have concentrated as solutions on the sea-floor, agglutinating portions of the floor and the debris thereon.

It seems highly probable that during the Lower Greensand-Gault transition period the phosphoric solutions were at first of insufficient strength to produce more than weakly cemented blebs of sediment, formation of the more indurated type of nodule being induced by phosphoric enrichment as the supply of detritus to the sea-floor increasingly diminished (Fig. 5A). Rather than a steady falling off in sedimentation, we may conceive alternating phases of positive accumulation and of no deposition, the intervals of no deposition becoming progressively more numerous or of longer duration until,

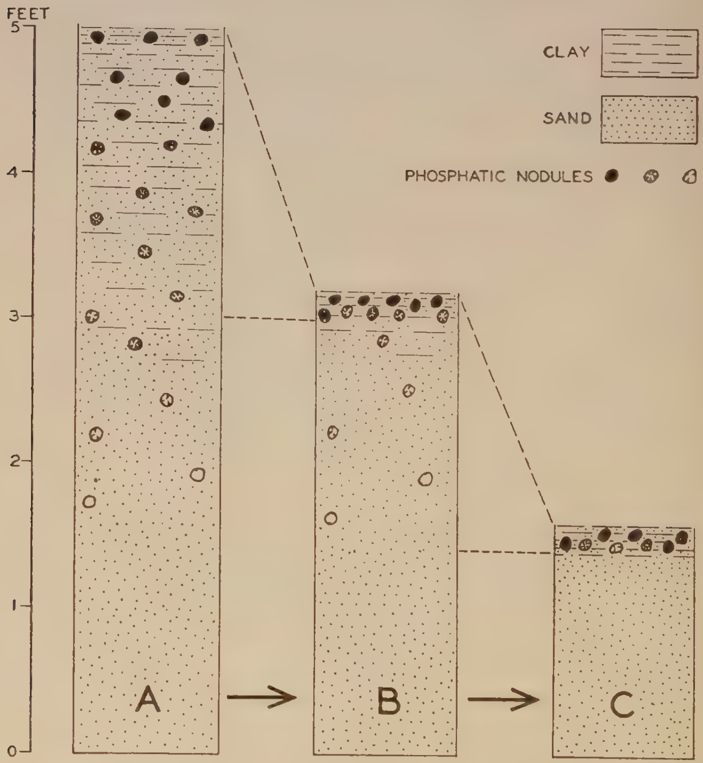


FIG. 5.—DIAGRAM ILLUSTRATING THE FORMATION OF A PHOSPHATIC NODULE-BED AT THE JUNCTION OF THE GAULT AND LOWER GREENSAND. In column A progressive phosphatisation is represented as increasing blackness of the nodules. Columns B and C show, in two stages, the effects of subsequent winnowing of the sediment by the action of currents.

from time to time, a maximum was reached. This seems to be indicated by the ill-graded constituents of the nodules at all levels, suggesting that repeated pauses in sedimentation gave opportunity for the reworking of previously deposited sheets of coarse and fine detritus prior to, or *pari passu* with, phosphatisation. Periods of maximum abatement in sedimentation corresponded to episodes of more active current scour during which those nodules which had passed the formative gel-stage were aggregated into seams, representing the siftings of perhaps several feet of strata (Fig. 5B).

If several generations of nodules were overrun in the process the *remanié* might contain a mixture of fossils from different palaeontological horizons.[1] And naturally, if current scour was intensive enough or sufficiently prolonged all evidence of the preliminary stages of inhibited deposition and intergradation of lithology was destroyed (Fig. 5C). The section may then show a sudden change in lithology and, because phosphatisation exercised a selective influence on the preservation of fossils, the abrupt appearance of a new fauna. Thus the concentration of a relatively small thickness of sediment may give the impression of an erosional disconformity at the junction of the nodule-bed and the underlying sands, when in fact the gap in the zonal sequence may be nil or negligible.

An example of this relationship is thought to be provided by the Gault and Lower Greensand in East Sussex, where the passage beds between the two series were telescoped during the lull in deposition which affected the peripheral areas of the geosyncline in early *tardefurcata* time. This accounts for the relatively sharp junction and explains the occurrence side by side in the basal nodule-bed of phosphatic nodules at different stages of formation. All the nodules are of *jacobi* age and since vestiges of the original passage beds are sometimes preserved beneath the nodule-bed (as at Selmeston), it may be surmised that the underlying sands are but slightly older.

PALAEONTOLOGICAL NOTES ON THE AMMONITES

GENUS : *HYPACANTHOPLITES* SPATH

Hypacanthoplites, with its flat, angular venter, is a distinctive genus and is highly characteristic of the Lower Albian. Judging by its occurrence in Germany, it reaches its zenith in the upper part of the *nodosocostatum* zone, is still abundant at the bottom of the *tardefurcata* zone, but fades out above the middle of that zone. It is found in the *mammillatum* zone as an occasional curiosity. The English Lower Albian is the repository of a rich fauna of *Hypacanthoplites* ; most of the species are new to science and none has been figured hitherto in the literature of this country.

---

[1] The oldest members of such condensed assemblages are not derived in the sense of the term as applied to fossils. Commonly it is the youngest, not the oldest, elements which have a " derived " appearance, since they were exhumed first and suffered the longest from current attrition.

When discussing the discovery of the *jacobi* fauna at Folkestone in 1939, Dr. Spath assigned these ammonites to the genus *Acanthohoplites* [33], overlooking the fact that they are the very group for which in 1923 he had created the name *Hypacanthoplites* [**27**, p. 64]. The true *Acanthohoplites* is as yet unknown in England.

HYPACANTHOPLITES RUBRICOSUS sp. nov.
Plate 14, Figs. 3–10

1939 *Acanthohoplites nolani-similis* (Breistroffer) Spath [**33**, p. 239].
1939 *Acanthoplites nolani-similis* Breistroffer, Casey [**4**, p. 365].
non 1935 *Acanthoplites* (*Hypacanthoplites*) *nolani-similis* Breistroffer, C.R. Soc. géol. France, No. 3, p. 29.

Material. The holotype, an external mould (G.S.M. 74094),[1] four paratypes (G.S.M. 74050, 74051, 74066, and 74069), and about twenty other specimens, all preserved in a brown or reddish-brown ferrugino-phosphatic rock (R. Casey Collection).

Horizon and locality. Lower (*rubricosus*) nodules, basement-bed of the Folkestone Beds, East Cliff, Folkestone.

Specific description. Fairly involute, discoidal ; compressed, polygonal whorl-section, with steep umbilical wall and flat venter. About ten umbilical tubercles to a whorl at 12–15 mm. diameter, each corresponding to a primary rib, with two or three intercalated secondaries, all slightly prorsiradiate and sigmoidal. Primaries accentuated on the inner half of the flank, frequently dichotomising half-way up the side (at the umbilical suture), the point of dichotomy coinciding with the position of a minute, sometimes obsolete, lateral tubercle. Ribs all feebly tuberculated at the ventral edges, leaving a smooth siphonal band.

As growth proceeds primary ribs become more numerous at the expense of secondaries, lose their tendency to dichotomise, and with disappearance of the lateral pustule (typically between 20 and 25 mm. diameter) take on greater flexuosity ; ribs begin to run straight across the venter, and umbilical tubercles lose definition. At 25 mm. diameter primary ribs number about 18 to a whorl, with usually two secondaries between each pair. Rounding of the ventral edges sets in between 35 and 40 mm. diameter ; at 45 mm. the venter is gently convex, and save for slight thickening of the primaries at the umbilicus, ribs are in uniform relief all round the whorl.

Suture-line as in other species of *Hypacanthoplites*, notably *H. hanovrensis* (Collet).

Dimensions :—	G.S.M. 74050	G.S.M. 74069
Diameter	30 mm.	–
Whorl-height	13.5 mm. (.44)	20 mm.
Whorl-thickness	–	16 mm.
Umbilicus	8 mm. (.27)	–

---

[1] The symbol G.S.M. precedes the registration numbers of specimens in the Geological Survey Museum.

A finely ribbed, compressed, variety, which tends to retain the accentuation on the inner portion of the primary ribs, is named var. *tenuiformis* nov. (type G.S.M. 74060). Another form departs from the type in its more vigorous lateral tuberculation on the inner whorls and is designated var. *papillosus* nov. (type G.S.M. 74091).

Remarks. H. rubricosus is a member of the species-group which contains *H. subrectangulatus* (Sinzow), *H. pygmaeus* (Sinzow), and *H. nolani-similis* (Breistroffer), from the Lower Albian of Transcaspia. None of these species shows, however, complete agreement with the English form. In *H. subrectangulatus*, for example, the ventral tubercles are more persistent ; *H. pygmaeus* has an ellipsoidal whorl-section ; while in *H. nolani-similis* the ribs are less flexuous and the umbilical tubercles remain conspicuous to a larger diameter than in the English form.

Early assumption of a convex venter in *H. rubricosus* is a feature shared by most of the ammonites in the *rubricosus* nodules and points to affinity with forms of the *nolani* subzone.

HYPACANTHOPLITES ANGLICUS sp. nov.

Plate 14, Figs. 1, 2a–c

Material. The holotype, an internal mould of the body-chamber with an impression of the earlier whorls in the matrix (G.S.M. 74097), one paratype (G.S.M. 84529), and two or three other examples, all preserved in black, sandy phosphorite (R. Casey Collection).

Horizon and locality. Upper (*jacobi*) nodules, basement-bed of the Folkestone Beds, East Cliff, Folkestone.

Specific description. Fairly involute, discoidal ; whorl-section compressed, polygonal, well-turned at the umbilicus and flattened on the venter. Flexuous ribs originate at first near the umbilicus, tending to bunch at umbilical tubercles ; later these tubercles become less conspicuous and the costation breaks up into alternately long (primary) and short (secondary) ribs, the latter springing from a point mid-way up the flank. At 40 mm. diameter there are 36 ribs to a whorl, all continuous across the venter with a slight sinus backwards. Ventro-lateral tubercles not discernible after about 30 mm. diameter.

Dimensions of holotype :—

Diameter in mm.	39
Whorl-height (in % of diameter)	38
Whorl-thickness (in % of diameter)	34
Umbilicus (in % of diameter)	31

A more boldly costate variety with about 32 instead of 36 ribs to the whorl is separated as var. *audax* nov. (type G.S.M. 74096).

Remarks. This species differs from *H. jacobi* (as restricted by Spath [33, p. 238]) chiefly in the relative coarseness of its costation and in the slight backward inflexion of the ribs on the venter ; the ventro-lateral tubercles appear to be lost at an earlier stage of growth than in *H. jacobi*, though this difference may be due to the fact that the Folkestone specimens are slightly rolled internal moulds. *H. anglicus* does not appear to be represented in the *jacobi* fauna at Vöhrm and Algermissen, but a suite of ammonites from the *acuticostata* subzone of Altwarmbuchen (Hanover), collected by Mr. E. V. Wright and kindly passed to the author for study, includes a closely comparable form. The more rectiradiate *H. trivialis* Breistroffer from the *tardefurcata* zone of the Perte-du-Rhone and Sainte Croix is not far removed from the present species ; an example of *H. trivialis* in the Sedgwick Museum with the ribs more flexed than the type (F 6561) is especially reminiscent of *H. anglicus*, though it possesses a deeper umbilicus and more persistent ventral tubercles.

GENUS : *DOUVILLEICERAS* DE GROSSOUVRE

DOUVILLEICERAS MAMMILLATUM (Schlotheim) emend. Spath

1923 *Douvilleiceras mammillatum* (Schlotheim), emend., Spath [**27**, p. 68, with synonymy].

The author follows Dr. Spath in using the combination *D. mammillatum* in its generally accepted sense, notwithstanding the fact that Walch's original figure, the type of Schlotheim's *A. mammillatus* and of the genus *Douvilleiceras*, may have been based on a specimen of *D. inaequinodum* (Quenstedt).

GENUS : *LEYMERIELLA* JACOB

LEYMERIELLA PSEUDOREGULARIS Seitz

? 1822 *Ammonites canteriatus* (Defrance) Brongniart *in* Cuvier and Brongniart : Environs de Paris, Plate vi, Fig. 7.

1908 *Leymeriella regularis* (Bruguière) Jacob, Ammon. Cret. Moyen., Mem. Soc. géol. France (Paléont.) xv, Plate vii, Fig. 23 (type).

1925 *Leymeriella regularis* (Bruguière) d'Orbigny sp., Spath [**27**, p. 86] in part.

1930 *Leymeriella pseudoregularis* Seitz, Zur Morphologie Ammon. Albien, Jahrb. preuss. geol. Landes., li, p. 24.

1947 *Leymeriella canteriatus* Defrance in Brongniart sp., Breistroffer [1, p. 70] (? excluding *A. canteriatus* Defrance, Brongniart sp.).

This species has been generally included in *L. regularis*, from which it differs in its more pronounced tuberculation and in developing flattened or grooved ribs only at an advanced stage of growth. To *L. pseudoregularis* must be referred Sharpe's original specimen of *Leymeriella* from Berwick Common, identified with *L. regularis* in previous publications [**32**, p. 429, **27**, p. 741, **15**, p. 523].

M. Breistroffer has used this species (under the name of *L. canteriatus*) to replace *L. regularis* as the subzonal index-fossil for the uppermost part of the *tardefurcata* zone. According to this authority, at Machéroménil (Ardennes), the locality of d'Orbigny's type, the true *L. regularis* is a rare form of the *mammillatum* zone and it is doubtful if it occurs at all in earlier strata [**1**, pp. 24, 54]. When discussing the faunal sequence of the Lower Albian in general, however, M. Breistroffer appears to discredit all records of *L. regularis* s.s. from below the *mammillatum* zone and to assume that they refer to *L. pseudoregularis*. The present author feels it important, therefore, to place on record that at Leighton Buzzard, Beds., at Folkestone, and elsewhere in the Weald where the relevant faunal bands are preserved and differentiated, *L. pseudoregularis* and a form indistinguishable from d'Orbigny's illustration of *L. regularis* are found side by side *below* the *mammillatum* zone. Thus, whatever the zonal origin of d'Orbigny's figured specimen, there is adequate evidence to show that, in England at least, *L. regularis* has its maximum abundance at the top of the *tardefurcata* zone and no change in zonal nomenclature is required.

Brongniart's *Ammonites canteriatus* may well be conspecific with *L. pseudoregularis*, as stated by Breistroffer, and those who consider that Brongniart's illustration of this ammonite is recognisable and suitable as a standard of comparison are at liberty to use the name. Until the type-specimen of *L. canteriatus* can be found and refigured it is recommended that the name be allowed to lapse.

GENUS : *PSEUDOSONNERATIA* SPATH

Pseudosonneratia is the direct ancestor of the group of ammonites typified by *Hoplites dentatus* (J. Sowerby).[1] In side view the two groups are alike, but *Pseudosonneratia* has the ribs continuous across the venter, whereas in *Hoplites* the ribs are interrupted by a distinct ventral groove, on each side of which the free ends of the ribs form a row of tubercles, the two rows arranged *en echelon*. *Pseudosonneratia* is extremely rare in this country ; a few typical examples have been found in the *monile* subzone at Folkestone, and forms transitional to *Hoplites* occur on a slightly higher horizon at Folkestone and elsewhere in the Weald.

Cf. *PSEUDOSONNERATIA LAFFRAYEI* Breistroffer

Cf. 1908 *Parahoplites steinmanni* Jacob, Ammon. Crét. Moyen., Mem. Soc. géol. France (Paléont.), Plate viii, Figs. 6a–b only.
Cf. 1947 *Pseudosonneratia laffrayei* Breistroffer [**1**, pp. 69, 71].

The three ammonites from the greensand seam near the base of Bed 1 of the Gault at Folkestone recorded by Dr. Spath [**27**, p. 734 footnote] include a form closely comparable with *P. laffrayei* B. This is one of the species transitional to *Hoplites*, the ribs being depressed along the siphonal line, foreshadowing the grooved venter of *H. dentatus* and its allies. The type is from the condensed *tardefurcata-mammillatum* zone of the Prés de Rencurel (Isère).

---

[1] Under the International Rules of Zoological Nomenclature *Hoplites*, Neumayr 1875, is invalid, but the name is here retained pending investigation of a claim to the International Commission for suspension of the rules in its favour.

The Folkestone specimen (G.S.M. 83164) is a fragment some 45 mm. in length showing five obtuse bullae at the umbilical margin, with four pairs of bifurcating, and one set of trifurcating, sigmoidal ribs. Most of the venter is missing, but enough is preserved to show that the ribs continue across the venter with a sinus forwards. The sectional outline is flat-sided and has a slight ventral depression. The ribs are a little thicker at the ventro-lateral edge and have a rather more decided projection forwards than in *P. laffrayei*—characters suggesting a more advanced stage of evolution towards *Hoplites*.

The other two Folkestone specimens (G.S.M. 83165–6) are similar to that described above, though perhaps belonging to a different species. Both show the beginning of ventral interruption of the ribs and could be accommodated equally well in *Pseudosonneratia* or in *Hoplites* (Fig. 6b).

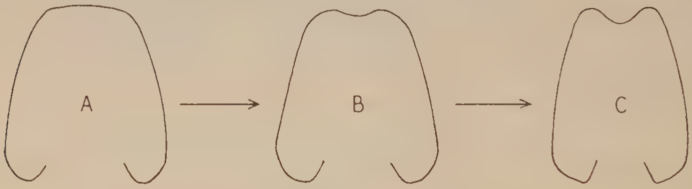


FIG. 6.—Outline whorl-sections of three ammonites from Copt Point, Folkestone, to show evolution of the ventral groove in *Hoplites*. (a) *Pseudosonneratia* sp., Folkestone Beds, main *mammillatum* bed (G.S.M. 84254); (b) unnamed intermediate form from the greensand seam near base of Bed 1 of Gault (G.S.M. 83166); (c) *Hoplites dentatus* (J. Sow.), nodule-bed just above greensand seam, Bed 1 of Gault (G.S.M. 1762). All x ¾.

The general resemblance between *Pseudosonneratia* and the group of *Ammonites deshayesii* (Leymerie MS.) d'Orbigny is sufficient to account for De Rance's reference to a square-backed form of *A. deshayesii* in the greensand seam near the base of the Gault at Folkestone.

GENUS : *SONNERATIA* BAYLE

SONNERATIA KITCHINI Spath

1923 *Sonneratia kitchini* Spath [**27**, p. 88–9].

When first described (from Leighton Buzzard, Beds.) this species was known only as a member of a condensed *tardefurcata-mammillatum* fauna, which led Dr. Spath to remark that as the beds containing *Sonneratia* are poorly developed in this country, separation into different horizons is not possible [**27**, p. 89]. The restriction of *S. kitchini* at Folkestone to a narrow band immediately below the main development of *D. mammillatum* and above that of *L. regularis* is thus important and future investigation may show this species to merit recognition as a subzonal index-fossil.

GENUS : *PROTOHOPLITES* SPATH

PROTOHOPLITES spp. nov.

Certain new forms from the " Sulphur Band " at Folkestone and equivalent beds inland, provisionally retained in *Protohoplites*, have the peripheral tubercles placed nearly parallel to the whorl-sides, the venter thus assuming the aspect of later genera like *Dimorphoplites* and *Callihoplites*. Others appear to connect directly with *Hoplites*. Material for description of these new forms is at present inadequate, but continued exploration at this level bids fair to increase substantially our knowledge of the evolution of the early Hoplitids.

REFERENCES

1. BREISTROFFER, M. 1947. Sur les Zones d'Ammonites dans l'Albien de France et d'Angleterre. *Trav. Lab. géol. Grenoble*, 26, pp. 1–88.
2. BRISTOW, H. W. 1875. *In* Topley : *Geology of the Weald*, p. 127.
3. CASEY, R. 1936. Recent Additions to the Albian Ammonoid Faunas of Folkestone. *Geol. Mag.*, 73, pp. 444–8.
4. ———. 1939. Upper Part of the Lower Greensand around Folkestone. *Proc. Geol. Assoc.*, 50, pp. 362–78.
5. CHAPMAN, F. 1898. The Probable Depths of the Gault Sea as indicated by its Rhizopodal Fauna. *Natural Science*, 13, No. 81, pp. 305–12.
6. (DE) R(ANCE), C. E. 1865. Phosphate Bed at Folkestone (letter on the). *Geol. Mag.*, 2, p. 527.
7. DE RANCE, C. E. 1868. On the Albian or Gault of Folkestone. *Geol. Mag.*, 5, pp. 163–71.
8. DESTOMBES, J.-P. and P. DESTOMBES. 1938. Note sur le Gault de Wissant. *Ann. Soc. géol. Nord*, 62, pp. 98–113.
9. EDMUNDS, F. H. 1928. The Wells and Springs of Sussex. *Mem. Geol. Surv.*
10. FITTON, W. H. 1836. Observations on some of the Strata between the Chalk and the Oxford Oolite in the South-east of England. *Trans. Geol. Soc.*, 4, pp. 103–390.
11. GOSSLING, F. 1929. The Geology of the Country around Reigate. *Proc. Geol. Assoc.*, 40, pp. 197–259.
12. HALLIMOND, A. F. 1922. On Glauconite from the Greensand near Lewes, Sussex ; the constitution of Glauconite. *Mineral Mag.*, 19, No. 98, pp. 330–3.
13. JUKES-BROWNE, A. J. 1900. The Cretaceous Rocks of Britain, Vol. 1. Gault and Upper Greensand of England. *Mem. Geol. Surv.*
14. KIRKALDY, J. F. 1933. The Sandgate Beds of the Western Weald. *Proc. Geol. Assoc.*, 44, pp. 270–311.
15. ———. 1935. The Base of the Gault in Sussex. *Quart. Journ. Geol. Soc.*, 91, pp. 519–37.
16. ———. 1937. The Overstep of the Sandgate Beds in the Eastern Weald. *Quart. Journ. Geol. Soc.*, 93, pp. 94–126.
17. LAMPLUGH, G. W. and F. L. KITCHIN, 1911. On the Mesozoic Rocks in some of the Coal Explorations in Kent. *Mem. Geol. Surv.*
18. ——— ——— and J. PRINGLE. 1923. The Concealed Mesozoic Rocks in Kent. *Mem. Geol. Surv.*

19. Mackie, S. J. 1856. *A Handbook of Folkestone.* Folkestone and London.
20. ———. 1860. Geological Localities: Folkestone. *Geologist*, 3, pp. 81–90.
21. Mantell, G. 1822. *The Fossils of the South Downs.* London.
22. ———. 1846. Descriptions of some Fossil Fruits from the Chalk Formation of the South-east of England. *Quart. Journ. Geol. Soc.*, 2, pp. 51–4.
23. Price, F. G. H. 1875. On the Lower Greensand and Gault of Folkestone. *Proc. Geol. Assoc.*, 4, pp. 135–50.
24. ———. 1875. On the Gault of Folkestone. *Quart. Journ. Geol. Soc.*, 30, pp. 342–66.
25. ———. 1879. *The Gault.* London.
26. Reid, C. 1898. The Geology of the Country near Eastbourne. *Mem. Geol. Surv.*
27. Spath, L. F. 1923–43. A Monograph of the Ammonoidea of the Gault. *Palaeont. Soc.* London.
28. ———. 1923. Excursion to Folkestone, with notes on the Zones of the Gault. *Proc. Geol. Assoc.*, 34, pp. 70–6.
29. ———. 1923. On the Ammonite Horizons of the Gault and Contiguous Deposits. *Summary of Progress Geol. Surv. for 1922*, pp. 139–49.
30. ———. 1930. On Some Ammonoidea from the Lower Greensand. *Ann. Mag. Nat. Hist. Ser.* 10, v., p. 417.
31. ———. 1933. Review of Spath 1930. *In Palaeont. Zentralbl.*, iii, No. 765, pp. 266–7.
32. ———. 1935. Field Meeting at Folkestone. *Proc. Geol. Assoc.*, 46, pp. 429–31.
33. ———. 1939. Problems of Ammonite Nomenclature. Part V: On *Acanthohoplites jacobi* (Collet) and the *Jacobi* Zone of the Folkestone Sands. *Geol. Mag.*, 76, pp. 236–9.
34. ———. 1941. On the Boundary between the Upper and Lower Cretaceous. *Geol. Mag.*, 78, pp. 309–15.
35. Topley, W. 1868. On the Lower Cretaceous Beds of the Bas Boulonnais, with notes on their English Equivalents. *Quart. Journ. Geol. Soc.*, 24, pp. 472–83.
36. ———. 1875. The Geology of the Weald. *Mem. Geol. Surv.*
37. White, H. J. Osborne. 1924. Geology of the Country near Brighton and Worthing. *Mem. Geol. Surv.*
38. ———. 1926. Geology of the Country near Lewes. *Mem. Geol. Surv.*
39. Wright, C. W. and E. V. Wright. 1942. Some New Sections and Fossils from the Folkestone Beds of the Farnham District. *Proc. Geol. Assoc.*, 53, pp. 86–7.

EXPLANATION OF PLATE 14

(All figures are natural size unless otherwise stated)

Fig. 1. *Hypacanthoplites anglicus* sp. nov. Side view of detached body-chamber of holotype. Folkestone Beds, basement-bed (*jacobi* nodules), East Cliff, Folkestone. (G.S.M. 74097.)

„ 2. *Hypacanthoplites anglicus* var. *audax* nov. Side view (a), peripheral view (b), and sectional outline (c) of type of variety. Horizon and locality as for Fig. 1. (G.S.M. 74096.)

„ 3. *Hypacanthoplites rubricosus* sp. nov. Plasticine impression of holotype-mould. Folkestone Beds, basement-bed (*rubricosus* nodules), East Cliff, Folkestone. (G.S.M. 74094.)

„ 4. *Hypacanthoplites rubricosus* sp. nov. Side view of paratype. Horizon and locality as for Fig. 3. (G.S.M. 74069.)

„ 5. *Hypacanthoplites rubricosus* sp. nov. Side view of paratype. Horizon and locality as for Fig. 3. (G.S.M. 74050.)

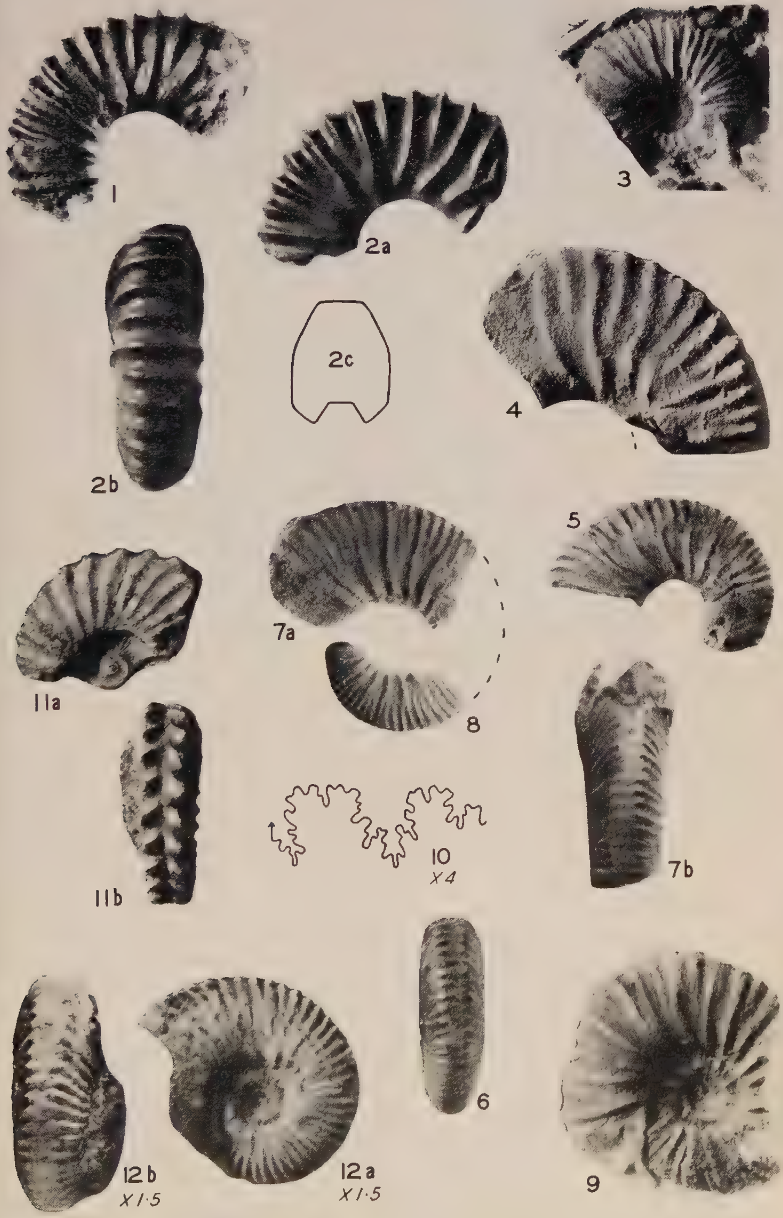


Photo: J. Rhodes.

Lower Albian Ammonites from Folkestone, Kent and Chalvington, Sussex.

[To face p. 296.

FIG. 6. *Hypacanthoplites rubricosus* sp. nov. Peripheral view of paratype. Horizon and locality as for Fig. 3. (G.S.M. 74066.)

,, 7. *Hypacanthoplites rubricosus* var. *tenuiformis* nov. Side view (a) and peripheral view (b) of type of variety. Horizon and locality as for Fig. 3. (G.S.M. 74060.)

,, 8. *Hypacanthoplites rubricosus* var. *tenuiformis* nov. Side view of another example from the same nodule as the original of Fig. 7. (Part of the same specimen ?) (G.S.M. 74061.)

,, 9. *Hypacanthoplites rubricosus* var. *papillosus* nov. Plaster impression of type-mould. Horizon and locality as for Fig. 3. (G.S.M. 74091.)

,, 10. *Hypacanthoplites rubricosus* sp. nov. Part of external suture-line (composite) enlarged X 4.

,, 11. *Leymeriella* aff. *regularis* (Bruguière, d'Orbigny sp.). Side view (a) and peripheral view (b) of example from the basement-beds of the Gault (*tardefurcata-mammillatum* nodules), Manor Farm Pit, Chalvington, Sussex. (G.S.M. 83868.)

,, 12. *Hypacanthoplites* aff. *elegans* (Fritel). Side view (a) and peripheral view (b) of " latex " rubber cast from an internal mould. Enlarged X 1.5. Basement-beds of the Gault (*jacobi* nodules). Locality as for Fig. 11. (G.S.M. 83870.)

DISCUSSION

DR. J. F. KIRKALDY, in a written contribution, heartily congratulated the author on the results of his careful examination of the Gault–Lower Greensand junction in East Sussex and East Kent. Marked attenuation of the Lower Cretaceous Beds, with in some cases overstep, as they were traced south-eastwards in Sussex, had already been described for the Weald Clay by Mr. Reeves and by the writer for the Lower Greensand as a whole. It was therefore very satisfactory to have such a detailed study of the behaviour of the Lower Albian strata. The general picture agreed well with the rapid lithological and faunal changes, which occurred in North France and Belgium, as the higher members of the Cretaceous System transgressed onto the slowly subsiding London–Ardennes massif.

The writer was awaiting with interest the further results of Mr. Casey's researches on the Folkestone Beds and hoped that in those areas, comprising the greater part of the outcrop, in which the beds were so sparingly fossiliferous, it would prove possible to relate the palaeontological zonal scheme to those distinctive lithological units, such as the Clay–Silt Band, traced by the late Mr. F. Gossling, which were, at present, the only means that the field geologist had of subdividing the Folkestone Beds.

MR. F. H. EDMUNDS, in congratulating the author on an outstanding paper the result of many years' patient collecting and research, remarked that the conception of an important break between the Lower Greensand and the Gault had now finally been demolished, and, with it, the justification for maintaining in this country the base of the Upper Cretaceous at the base of the Gault, rather than at the base of the Chalk in conformity with Continental usage.

In making a geological map of a restricted area such as that of a 1-inch New Series sheet, the map-maker must, of necessity, adopt a lithological basis for his boundary lines, regarding Gault still as clay, and the Folkestone Beds (the top subdivision of the Lower Greensand) as sand ; yet the Geological Map taken as a whole is related to a time scale, and in the future the author's work will have to be taken into consideration in the preparation of the interpretive vertical scaled sections for those geological maps which include the Cretaceous formations.

MR. C. W. WRIGHT congratulated the author on his lucid exposition of some of the results of his recent valuable researches. He understood that the author hoped soon to publish papers on further aspects of his work. The Association was to be congratulated also on the success of researches which had been supported by grants from its funds, and members would look forward with lively anticipation to hearing future papers by the author.

The AUTHOR, in reply, expressed his thanks for the cordial reception of the paper, which reception added to the encouragement already given him by the Association. He welcomed Mr. Edmund's remarks on the boundary between the Upper and Lower Cretaceous and reminded members that the practice of including strata of Gault age in the Lower Cretaceous, followed in most other countries, had been endorsed by a decision of the International Commission on Geological Nomenclature at Zurich in 1883 (See *Report of 3rd International Geological Congress*, 1885, pp. 282–4, 329). The desirability of accepting this decision had been impressed upon British geologists by Dr. L. F. Spath (*Geol. Mag.*, 1941, pp. 309–15).

As Mr. Wright had intimated, the present paper was introductory to more comprehensive studies of the Folkestone Beds and basal Gault in the Weald. In a future communication the author hoped to show that despite the paucity of fossils throughout the inland outcrop of the Folkestone Beds, the lithological units mentioned by Dr. Kirkaldy could be related to the zoned sequence at Folkestone.

FIELD MEETING AT LEWES, BERWICK, AND NEWHAVEN

Saturday, 16th July, 1949

Report by the Director : I. E. Higginbottom, B.Sc., A.R.C.S., F.G.S.

[*Received* 1*st February*, 1950]

THE party, consisting of eleven members and friends, met outside Lewes Station at 11 a.m., and went on foot to the Castle, climbing the steep side of the valley of the Lewes Winterbourne, a typical perennial stream, then dry. From the roof of the Castle Keep the Director pointed out the main geomorphological features and drew comparisons between this and corresponding views across the Weald from its northern side. The absence of any prominent escarpment of the Lower Greensand was particularly striking, and, as a result, the hills of the Forest Ridge, twelve to fifteen miles away, were unobscured.

The town of Lewes stands on a chalk spur projecting eastwards into the Ouse valley, which is thereby restricted in width to a few hundred yards. The precipitous hillside opposing the end of this ridge, represents a river-cliff whose profile appears to plunge under the alluvium, and is presumably graded to a buried channel of the river. The Cliffe, as it is termed, is breached by The Coombe, a straight dry valley ending in a double bifurcation when followed " upstream " for half a mile. The origin of this valley has been the subject of controversy for over a century ; once thought the product of a strike-fault [1*], or a steep flexure [2], it is now considered by Gaster [3] to have been formed independently of any structure. Attention was aroused by the fact that the Ouse flows through a narrow valley at Lewes, whereas a little downstream the much wider subsequent valley of Glynde Reach carries only a narrow brook, seemingly a "misfit". It was asked whether the course of the Ouse through Lewes was the result of backward cutting by a resequent stream until a hypothetical detour of the main consequent flow through Glynde Reach was short-circuited, so producing the outlier of chalk downland comprising Cliffe Hill and Mount Caburn. These variations in valley width can, however, be explained on structural grounds ; because the Glynde Reach valley is anticlinal and eroded along the strike of the Upper Greensand and Gault, its greater width would thus result. In the same way may be explained the narrowness of the Ouse valley at Lewes, where it passes entirely through Chalk folded down in the complementary Mount Caburn syncline.

Other land-forms of interest were seen in fragments of the

---

* For list of References, see p. 301.

230-foot platform [4, 5] near Kingston, and in the conspicuous bench at 400 feet [4] in the profile of Firle Beacon.

The party then walked past the conspicuous chalkpits of South Street to the quarry behind the " Fox " at Southerham. Chalk of the *Holaster subglobosus* zone appears in the long narrow entrance, though the main excavation, to the south, is on a lower horizon, and yields *Schloenbachia varians*. This results from the 10° northerly dip shown here, indicating the southern limb of the Mount Caburn syncline. Near the entrance to the quarry numerous broken fragments of cephalopods are to be found, derived presumably from the bed described by Osborne White [2]. The great majority of these can be referred to the genera *Schloenbachia*, *Acanthoceras*, *Mantelliceras*, *Turrilites*, *Scaphites*, and *Cymatoceras*, and pyritised casts of the sponge *Plocoscyphia labrosa* occur.

Climbing by way of Ranscombe Hill, the party gained the summit of Mount Caburn, which commands an extensive view across the anticlinal valley of Glynde Reach. Whilst descending to Glynde village an exposure of " scarp drift " [4] was indicated, and members halted for a short while at the large chalkpit on the south-east flank of the hill. This pit exposes nearly the whole of the *Terebratulina lata* zone, whilst the lowest twenty feet or so of the *Holaster planus* zone is also visible at the top. The respective zone-fossils are plentiful, and early forms of *Micraster* (*cor-bovis*, *leskei*, and *praecursor*) may be collected here. The top few feet of the *lata* zone (accessible from the wide ledge) are noteworthy for being prolific of penta-radiate crinoid columnals.

Lunch was taken in the Trevor Arms Hotel at Glynde, after which the party travelled by train to Berwick Station, where the pit of the Cuckmere Brick Co. was visited. This shows glauconitic Sandgate Beds resting non-sequentially upon Weald Clay, a *remanié* bed of phosphatic nodules intervening and in which a fruitless search for ammonites ensued. This section has been enlarged since the Association last visited it [7] but the features observed remained substantially the same.

On leaving Berwick the field-path to Selmeston was followed, where pits in the Folkestone Beds were visited, and the general characters of that formation described by the Director. In the western face of the old pit by the church the Gault–Folkestone Beds junction was demonstrated by the nodule bed on this horizon, which was unproductive, except of fossil wood [8]. This pit is a notable Mesolithic site, and flint flakes derived from this culture were found by some of the members.

After climbing the bostal[1] leading south from Bo-peep, near Alciston, the summit of the South Downs scarp was attained, and the scenic features characterising this range were pointed out [4, 5]. The track down the dip-slope to Denton was then followed, and tea taken on reaching this village. Here Mr. E. C. Martin proposed a vote of thanks to the Director, before the more stalwart members visited the cliff-section at Newhaven. Here Eocene Beds (as an outlier from the Hampshire Basin) overlie, with a slight angular discordance, Chalk of the *quadratus* zone [9]. A bed, two feet thick, of green-stained flint breccia, underlain by about the same thickness of clay with gypsum crystals and earthy masses of websterite, forms the base of the series, which is referred to the Landenian and Ypresian stages. The sequence continues with thirty feet of marine glauconitic sandstone, devoid of fossils, but judged from its fossiliferous analogues across the Channel to be equivalent in age to the Woolwich Bottom Bed. Above, are twelve feet of grey and brown estuarine clays of Woolwich type (Upper Landenian) crowded with fossils, the most conspicuous being *Ostrea bellovacensis* (as thick banks), *Cyrena cuneiformis*, and "*Melania*" *inquinata*. The Ypresian (London Clay) series above this group was not seen, but it was mentioned that this and the underlying Landenian clays were responsible during the late war for much trouble from landslipping [10]. After spending a very short while at this exposure, members returned to Lewes, *via* Newhaven, at 7.30 p.m.

---

[1] *Bostal* is a word used in Sussex for a sunken track ascending the escarpment of the South Downs.

REFERENCES

1. LYELL, C. 1830–3. *Principles of Geology*, pp. 300–1.
2. WHITE, H. J. OSBORNE. 1926. The Geology of the Country around Lewes, *Mem. Geol. Surv.*
3. GASTER, C. T. A. 1937. Report of Field Meeting at Lewes, Sussex. *Proc. Geol. Assoc.*, 48, p. 354.
4. BULL, A. J. 1936. Studies in the Geomorphology of the South Downs. *Proc. Geol. Assoc.*, 47, p. 99.
5. SPARKS, B. W. 1949. The Denudation Chronology of the Dip-Slope of the South Downs. *Proc. Geol. Assoc.*, 60, p. 165.
6. KIRKALDY, J. F. 1937. The Overstep of the Sandgate Beds in the Eastern Weald. *Quart. Journ. Geol. Soc.*, 93, p. 94.
7. BULL, A. J. and J. F. KIRKALDY. 1936. Field Meeting at Berwick and Hellingly, Sussex. *Proc. Geol. Assoc.*, 47, p. 265.
8. KIRKALDY, J. F. 1935. The Base of the Gault in Sussex. *Quart. Journ. Geol. Soc.*, 91, p. 519.
9. ELSDEN, J. V. 1910. The Tertiary and Post-Tertiary Deposits of the Sussex Coast. *Geology in the Field*, p. 270.
10. WARD, W. H. 1948. A Coastal Landslip. *Proc. 2nd Int. Conf. Soil Mechanics and Foundation Engineering*, Rotterdam. 2, p. 33.

FIELD MEETING AT EYNSFORD, KENT

Saturday, 24th September, 1949

Report by the Directors : A. G. Bell, I.S.O., B.Sc., F.G.S. and R. J. Bell, A.M.I.C.E.

[*Received 8th February,* 1950]

A PARTY numbering thirty-five met at Eynsford station and first, under the guidance of Mr. R. J. Bell, inspected the Eynsford Well Station of the Metropolitan Water Board, situated in the valley of the River Darent.

At this Station, 350 feet apart, are a well continued by a borehole 300 feet deep and a borehole 350 feet deep, penetrating the following strata :—

Alluvium ...	21 feet
Upper Chalk ...	69 feet
Middle Chalk ...	200 feet
Lower Chalk ...	40 feet

The borehole terminates in Melbourn Rock. Abundant water is produced. Each set of pumping machinery has a capacity of two million gallons per day.

The party then walked up the valley, noticing, a few feet above the present flood plain, a well-marked terrace, which can be traced for more than half a mile.

At the north gate of Lullingstone Park the excavation of a Roman villa, conducted by the Darent Valley Archaeological Research Association, which has revealed fine mosaic pavements of fourth century date, was inspected. Coombe Rock was exposed in one of the trenches and it was noticed that several feet of hill-wash had accumulated on the site both before and since Roman times, and had encroached considerably on the alluvium of the valley.

Tea was obtained at Lullingstone Castle, where most of the party inspected a Silk Farm established there by Lady Hart-Dyke.

A Chalk pit in the zone of *Holaster planus* was next visited and some fossils were collected. Before the party dispersed Dr. G. W. Himus moved a vote of thanks to the Directors.

INDEX TO VOLUME 61

PAGE

Abbey Wood (Charlton and Plumstead) Field Meeting Report 218
Accounts of the Geologists' Association 87, 92
Albian and Cenomanian, crabs 13
Albian of Sussex and East Kent 268, 289
Allerd Oscillation 122
Annual Report of Council for 1949 87
ASHCROFT, F. N. Obituary ... 109
Atlantic climatic phase ... 124

BADEN-POWELL, D. F. W. Report on Lowestoft district Field Meeting (with Appendix on the marine mollusca of the Corton Beds) 191
BARNARD, T. and J. G. CAPEWELL. Report on Whitsun Field Meeting (1948) at Lyme Regis 156
Barton and Milford-on-Sea Field Meeting 161
Basin, deep-sea floor 28, 34
Bathymetrical charts, recent ...28, 31
Beinn Spionnaidh, corries ... 149
BELL, A. G. and R. G. BELL. Report of Eynsford, Kent, Field Meeting 302
Berwick, Lewes and Newhaven Field Meeting 299
Blockley station (Lower Lias) ... 259
Boreal phases 122
Brazil, quartz crystals in ... 7, 9
BROWN, E. E. S. Postscript to Presidential Address, 1949 ... 12
———, The Story of Quartz Crystals (Presidential Address) 1
BULL, A. J. Gravitational Sliding 198
Burleigh 250
BURNABY, T. P. Tubular Chalk Stacks of Sheringham... 226
BURTON, E. St. J. and D. CURRY. Report on Barton and Milford-on-Sea Field Meeting 161

CAPEWELL, J. G. (and T. BARNARD). Report on Whitsun Field Meeting (1948) at Lyme Regis 156

PAGE

CASEY, R., awarded G. W. Young Fund 88
———, (discussion) 298
———, Junction of Gault and Lower Greensand in East Sussex and at Folkestone, Kent 268
Castle Lime Works 219
Cenellipsis Haeckel 209
Cenosphaera Ehrenberg... ... 208
Chalk, solution of, Mimms Valley 219
———, solution pipes (Chalk stacks), Sheringham 226
———, Weybourne Crag unconformity 227, 232
Chalvington 276, 282
CHANNON, P. J. New and enlarged Jurassic Sections in the Cotswolds 242
———, Report of Cotswold Field Meeting 261
Char, R., development of valley of 158
Charlton, Plumstead and Abbey Wood Field Meeting Report... 218
Chronology of the Deglaciation of Scotland. By A. D. Lacaille 121
Cirencester 257
Climatic change, indicated by foraminifera 29, 58
Cooper's Hill 242
Copt Point 270, 272
Coring, deep-sea 28, 49
Corries, in Sutherland 145
Corton Beds, marine mollusca ... 195
Cotswolds, Jurassic sections ... 242
———, Field Meeting ... 261
COX, L. R. Report of Cotswold Field Meeting 261
Crabs, Dromiacean, from the English Cretaceous 13
Cranstackie, corries 149
CURRY, D. C. (and E. St. J. BURTON). Report on Barton and Milford-on-Sea Field Meeting 161
Cyphonotus Bell 20

Dagham Downs 258
DAVIS, A. G. Radiolaria of the Hawasina Series of Oman 206
Deep (oceanic) 35

PAGE
Deep-sea deposits, chemistry of 28, 47, 50
———, mineralogy of ... 53
———, texture of 45, 52
Deep-sea floor, morphology ...28, 32
———, ———, origin and dating 35
———, ———, influence on sedimentation 44
———, recent investigations of, By J. D. H. Wiseman and C. D. Ovey 28
Deep-sea sediments 44
Deglaciation, of Scotland ... 121
———, ———, fauna ... 133
Diaulax Bell 24
Douvilliceras de Grossouvre ... 292
Dromiacean Crabs from the English Cretaceous 13
Dryas periods 122
Dynomenidae, evolution ... 26

East Cliff, Folkestone 268, 283, 290
East Sussex, Gault—Lower Greensand ... 268, 276, 284
EASTWOOD, T. (President) ... 187
Echo sounding 28, 31
EDMUNDS, F. H. 297
Ellipsidium Haeckel 209
EPPS, F. J., Report of Charlton, Plumstead and Abbey Wood Field Meeting 218
Erratic Rocks on Deep-sea Floor 73
Eynsford, Kent, Field Meeting... 302

Fernhurst, Sussex, features in structure and geomorphology 165
Field Meetings 1949 ... 89, 104
Field Studies, Council for Promotion of 91
Flint implements, Weybourne Crag 238
Foinaven, corries 145
Foraminifera, planktonic, significance in cores 29, 57
———, ———, as temperature-indicators 29, 64
Forests, in Scotland 122
Foulerton Award 91, 97

GARWOOD, E. J. Obituary ... 109
Gault—Lower Greensand, East Sussex and Folkestone ... 268
Goniodromites Reuss 16
Gravitational Sliding. By A. J. Bull 198
GREEN, J. F. N. Obituary ... 112
Guyot 34

PAGE
Hawasina Series of Oman ... 206
———, age of 215
———, list of radiolaria from 214
HAYWARD, J. F. Report of Field Meeting, "Two buried rivers—an afternoon in London" 225
HERRIES, Mrs. R. S. Obituary 113
HIGGINBOTTOM, I. E. Report of Lewes, Berwick and Newhaven Field Meeting ... 299
Holebourne and Wallbrook rivers, Field Meeting 225
HOLLINGWORTH, S. E. ... 188
HUME, W. F. Obituary ... 113
Hypacanthoplites Spath 268, 289
Hythe Beds, around Fernhurst, Sussex 165
———, base 167
———, dislocations 177

Icebergs in Atlantic 73

Junction of Gault and Lower Greensand in East Sussex and at Folkestone. By R. Casey ... 268
Jurassic sections, Cotswolds ... 242

KENNETT - BARRINGTON, G. N. E. Obituary 117
KIRKALDY, J. F. (discussions) 187, 297
———, Report of Water End, North Mimms, Field Meeting 224
———, Solution of the Chalk in the Mimms Valley, Herts.... 219

LACAILLE, A. D. Chronology of the Deglaciation of Scotland 121
LAKE, Phillip. Obituary ... 117
Landslides 198
LANG, W. D. Post-Eocene Development of the Valley of the Char 158
Late-Glacial period 121
Lewes, Berwick and Newhaven Field Meeting 299
Leymeriella Jacob 292
Library, Report 89
———, List of Donations ... 107
Lithocampe Ehrenberg 214
LOVELY, H. R. 187
Lower Greensand, around Fernhurst, Sussex 165
Lower Greensand—Gault, East Sussex and Folkestone ... 268

PAGE

Lowestoft District Field Meeting Report 191
Lyme Regis Field Meeting ... 156

"Mass-Movements" around Fernhurst, Sussex 185
May Hill (and Woodhope district) Field Meeting Report ... 202
Meyenella gen. nov. ... 206, 211
Midland Group, Report ... 90
————, Meetings and Field Meetings 106
Milford-on-Sea (and Barton), Field Meeting 161
Mimms Valley, solution of Chalk 219

New and enlarged Jurassic sections in the Cotswolds. By P. J. Channon 242
Newhaven, Lewes and Berwick Field Meeting 299
North Staffordshire Group, formation 90
————, Report 107
North-East Lancashire Group, Report 90
————, Meetings and Field Meetings 106

Obituary Notices, 1949: Ashcroft, F. N.; Garwood, E. J.; Green, J. F. N.; Herries, Mrs. R. S.; Hume, W. F.; Kennett-Barrington, G. N. E.; Lake, P.; Reynolds, S. H.; Sibley, Sir T. F.; Tunbridge, E. W. 109
Oceans, history of 28, 49
OVEY, C. D. (and J. D. H. WISEMAN). Recent Investigations on the Deep-sea Floor 28

Palaeocanthus gen. nov. ... 214
Parph, corries 152
Peat-mosses and Peat-filled lakes in Scotland 132, 133
Phosphatic nodules 286
Plagiophthalmis Bell 13
Planktonic foraminifera, in cores 57
————, as temperature indicators 29, 64
Pleistocene deposits of deep-sea floor 29, 69
Pliocene deposits of deep-sea floor 69
Plumstead (Charlton and Abbey Wood) Field Meeting Report 218

PAGE

POCOCK, R. W. Report on Woolhope and May Hill Whitsun Field Meeting (1949) ... 202
Pollen-analysis, in Scotland 121, 122
Post-Eocene Development of the Valley of the Char. By W. D. Lang 158
Post-Glacial beds in Scotland ... 127
————, raised beach 130
Presidential Address, 1949, postscript to 12
————, 1950 1
Protohoplites Spath 295
Pseudosonneratia Spath ... 293

Quartz Crystals, Brazilian mining and reserves 7, 9
————, Defects and examination 3
————, "Irregular" ... 6
————, modern uses and recent demands 2
————, sources of supply ... 8
————, The story of. By E. E. S. Brown 1

Radioactivity of marine sediments and water 29, 54
Radiolaria of the Hawasina Series of Oman. By A. G. Davis 206
Radiolarites 206
Recent Investigations on the Deep-sea Floor. By J. D. H. Wiseman and C. D. Ovey ... 28
Report of Session, 1949... ... 96
Reunion, List of Exhibits ... 102
REYNOLDS, S. H. Obituary ... 117
Rhizoconcretions 237
Ridge, deep-sea floor 28, 33
Rise, deep-sea floor 33

Salperton 253
Scotland, deglaciation of ... 121
Sea-mount 33
Sea-water, titanium in 29, 51
————, radioactivity of ... 54
Sedimentation, deep-sea floor ... 44
Selmeston 278, 282
Shenley Hill, Limestone... ... 13
Sheringham, Chalk Stacks ... 226
SIBLY, Sir Thomas F. Obituary 118
Sill, deep-sea floor 33
Slumping, deep-sea floor ... 45
Snowshill Hill 249
Solution of the Chalk in the Mimms Valley, Herts. By J. F. Kirkaldy 219

PAGE
Solution pipes (Chalk Stacks) of Sheringham 226, 230
Some Corries of North-west Sutherland. By H. R. Thompson 145
Some Dromiacean Crabs from the English Cretaceous. By C. W. and E. V. Wright ... 13
Some Features in the Structure of Geomorphology of the country around Fernhurst, Sussex. By S. W. Wooldridge 165
Sonneratia Bayle 294
South Downs Field Meeting ... 163
SPARKS, B. W. Report on South Downs Field Meeting... 163
Spongolonche Haeckel 211
Staurodoras Haeckel 209
Stopes Memorial Fund 88, 97
Story of Quartz crystals. By E. E. S. Brown (Presidential Address) 1
Sutherland, North-west, corries of 145

Table-mount, deep-sea floor ... 33
Tetbury 255
THOMPSON, H. R. Some Corries of North-west Sutherland 145
Titanium in sea water 29, 51
Trench, deep-sea floor 34
Tripocyclia Haevkel 210
Trough, deep-sea floor 34
Trustees of the Association ... 91
Tubular Chalk Stacks of Sheringham. By T. P. Burnaby ... 226
TUNBRIDGE, E. W. Obituary 119

PAGE
VENABLES, E. M., recipient of Foulerton Award 97

Wallbrook and Holebourne rivers, Field Meeting 225
WARD, W. H. 190
Water End 219
———, Field Meeting ... 224
Weald Clay around Fernhurst, Sussex 165, 168
Weald Research Committee ... 90
———, Report No. 41 (Fernhurst) 165
West Runton, Chalk Stack near 228
Weybourne Crag 226
———, Chalk unconformity and land surface, 226, 227, 232, 239
———, flint implements ... 238
WISEMAN, J. D. H. and C. D. OVEY. Recent investigations on the Deep-sea Floor ... 28
WOOLDRIDGE, S. W. Some Features in the Structure and Geomorphology of the country around Fernhurst, Sussex 165
Woolhope district and May Hill Field Meeting Report... ... 202
WRIGHT, C. W. and E. W. WRIGHT. Some Dromiacean Crabs from the English Cretaceous... 13
WRIGHT, C. W., discussion ... 297

Xiphosphaera Haeckel 209

Young Fund, award 88